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1979

GEOLOGIC CONDITIONS AFFECTING SAFE BITUMINOUS COAL MINING IN PENNSYLVANIA: SELECTED PAPERS

Compiled by
Samuel I. Root

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

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PENNSYLVANIA GEOLOGICAL SURVEY
FOURTH SERIES
HARRISBURG

1979

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GEOLOGIC CONDITIONS AFFECTING SAFE BITUMINOUS COAL MINING IN PENNSYLVANIA: SELECTED PAPERS

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INTRODUCTION

Pennsylvania historically gave birth to both the coal industry and oil and gas industry, which have served as the basis of our highly industrialized society. However, known reserves of oil and gas in the commonwealth are small, whereas substantial reserves of coal still remain. It has been recently estimated (Edmunds, 1972) that as much as 22 billion tons of bituminous coal in seams greater than 28 inches is recoverable in the state. Of that amount, about 8 to 9 billion tons is readily minable. It is clear from current world events that coal is destined to become an increasingly more valuable natural resource. The extraction of coal both safely and expeditiously is the common goal of this industry. Knowledge and understanding of the geologic conditions that affect mining of the coal helps achieve this goal.

Bituminous coal deposits formed as peat accumulations in a complex series of shifting environments of nonmarine and marginal marine character. Consequently, except for the remarkable Pittsburgh seam, coals may show abrupt variation in physical character and chemical composition, and the associated roof and seat rock may change character equally abruptly.

After alteration of the peat to coal, stresses related to the development of the ancestral Appalachian Mountains produced a system of fractures or joints in the coal strata. Joints, then, are natural planes of weakness along which rocks tend to separate, and in mining operations they may cause collapse of the roof.

Hydrocarbon gases, particularly methane, are generated during the conversion of peat to coal. During mining of the coal small amounts of methane gas are frequently liberated at the working face, but on occasion large amounts are catastrophically liberated, resulting in an explosion.

It is the interaction of these geologic conditions that may produce safety problems in the mining of coal. In the bituminous coal fields of Pennsylvania there are two main types of mining difficulties affected by geology. First, there are roof fall problems either associated with weak or unstable roof rock or attributable to the presence of joint systems that weaken the roof rock. Second, the unexpected liberation of a large amount of methane gas poses the danger of an explosion.

Of course, not all roof falls are attributable to geologic conditions. Some are affected by mine design and extractive procedure. During mining of the Pittsburgh coal Dahl and Parsons (1972) observed that rock fall severity was affected by room width and extraction ratio in addition to geologic factors of strata curvature, overburden thickness, and rider seams.

In attempting to predict probable roof fall areas in advance of mining, Overbey and others (1973) cited twelve geologic factors that contribute to roof falls. They are:

1. Bedding planes and joints.
2. Planes of weakness, faults, and discontinuities.
3. Fracture systems underlying stream channels.
4. Groundwater seepage through fracture zones.
5. Gas and water pressure in the strata overlying shale in the mine roof.
6. Voids in roof rock caused by oxidation of pyritic veins.
7. Presence of clays in floor and roof layers, particularly montmorillonite and expandable illite.
8. Clay veins in the roof and coal.
9. Shale or sand lenses in the roof.
10. Thin sections of draw slate in the roof.
11. Fossils imbedded in roof rock.
12. Stresses in the rock.

During the past few years a number of reports have been published that address themselves directly to many of these geological factors. While the geologic principles may not be entirely new, their specific applications will serve as guidelines to the safe and efficient mining of coal. For example, Campbell and others (1975) describe Peabody Coal's Simco mine no. 5, where roof conditions were so bad that even with roof bolts, full roof planking, and rails every few feet, the roof would cave. It was determined that the mine was being developed so that entries and crosscuts paralleled a set of joints. The mine was abandoned and a new drift entry made a few hundred feet north that bisected the set of joints, and subsequently no major support problems were encountered. The recognition that development of mine workings parallel to fractures maximizes stress conditions in a weak roof enabled a simple directional change to be made in the mine layout that minimized stress conditions, resulting in safer working conditions and less expensive mining costs.

Seven papers were reproduced here with the expectation that the geologic information and its application will be used by all segments of the coal industry. The papers have been selected because they deal directly with major aspects of those geologic factors that affect bituminous mining in Pennsylvania. It is felt that these papers together sum up the current state of the art. The papers are:

1. *Geologic Causes and Possible Preventions of Roof Fall in Room-and-Pillar Coal Mines*, by B. H. Kent, 1974, Pennsylvania Geological Survey, 4th ser., Information Circular 75, 17 p. (Plate 1 has not been reproduced).
2. "Channel Sandstones in Coal," by G. B. Glass, 1971, Pennsylvania Geology, v. 2, no. 5, p. 4-6.
3. *Roof Rock Structures and Related Roof Support Problems in the Pittsburgh Coalbed of Southwestern Pennsylvania*, by N. N. Moebs, 1977, U. S. Bureau of Mines Report of Investigations 8230, 30 p.
4. *Geologic Factors Causing Roof Instability and Methane Emission Problems: The Lower Kittanning Coalbed, Cambria County, Pa.*, by C. M. McCulloch and Maurice Deul, 1973, U. S. Bureau of Mines Report of Investigations 7769, 25 p.
5. *Geology and Methane Content of the Upper Freeport Coalbed in Fayette County, Pa.*, by P. F. Steidl, 1977, U. S. Bureau of Mines Report of Investigations 8226r, 17 p.
6. *Geologic Investigations of Underground Coal Mining Problems*, by C. M. McCulloch, P. W. Jeran, and C. D. Sullivan, 1975, U. S. Bureau of Mines Report of Investigations 8022, 30 p.
7. *Selected Geologic Factors Affecting Mining of the Pittsburgh Coalbed*, by C. M. McCulloch, W. P. Diamond, B. M. Bench, and Maurice Deul, 1975, U. S. Bureau of Mines Report of Investigations 8093, 72 p. (pages 42-51 and 63-71 not reproduced).

In general terms, papers 1, 2, 3, 4, and 6 present information on the various types of rock that affect the strength of mine roofs. Both large- and small-scale sedimentary structures that may indicate unstable or irregular roof in advance of mining are identified. Papers 2, 3, 4, and 5 present information on the relation of joint systems to roof rock conditions. They indicate where joint concentrations may cause roof falls, and how to lay out mine workings to compensate for such effects. Papers 5, 6, and 7 concern the occurrence of methane in mines. They describe how abnormally high pressure zones of methane are built up and identify the structural and lithologic settings where such zones can be anticipated to occur. Highlights of these papers are presented in the following paragraphs.

Studies of the Pittsburgh coal by Kent (Paper 1. *Geologic Causes and Possible Prevention of Roof Fall in Room-and-Pillar Coal Mines*) reveal two patterns of roof falls. A unidirectional pattern of roof falls is related to a set of northeast-trending joints that weakens the roof rock in that direction. After mine workings were driven oblique to this joint set there was a significant reduction in the incidence of roof falls. Bidirectional roof falls are developed in zones of disrupted shales along margins of channel-fill sandstone. This zone of weakened rock may be partially compensated for by driving the mine workings normal to the trend of the channel sandstone and leaving longitudinal support pillars in these zones.

Glass (Paper 2. "Channel Sandstones in Coal") mapped a typical Kittanning channel-fill sandstone in Centre County. The three-dimensional geometry and size of this channel are typical of many such bodies in the bituminous coal fields. By outlining these channels prior to mining it is possible to develop the mine to account for unsafe roof rock adjacent to the channel and reduce difficulties in driving workings through the harder sandstones in the channel.

Minor sedimentary structures in roof rock are related by Moebs (Paper 3. *Roof Rock Structures and Related Roof Support Problems in the Pittsburgh Coalbed of Southwestern Pennsylvania*) to the type of roof rock support that may be anticipated. Particularly bad roof conditions are associated with small-scale channels, scours, and slickensides. Unstable roof is also associated with flaggy, poorly cemented sandstones weakened by coaly or micaceous laminae. These sedimentary structures and lithologies are readily recognized in drill core or mine workings and, where present, should be accounted for in mine development.

Roof falls may liberate large volumes of gas from the overlying beds. Such conditions were encountered in the Lower Kittanning coal by McCulloch and Deul (Paper 4. *Geologic Factors Causing Roof Instability and Methane Emission Problems*). Areas of extensive roof fall above the Lower Kittanning coal occur where the interval to the overlying coal is less than 30 feet and is composed of thin layers of limestone, shale, and sandstone. Roof falls are also concentrated adjacent to the margin of channel-fill sandstone. It is possible to recognize such areas in advance of mining and compensate for the associated effects.

As part of a study on degasification, Steidl (Paper 5. *Geology and Methane Content in the Upper Freeport Coalbed in Fayette County, Pa.*) accumulated a considerable amount of data on cleat (joints) throughout the county. He established that face cleat trends N72W and butt cleat trends N21E. These joints define an orthogonal system whose orientation is constant throughout the county. Other studies confirm similar relations throughout the bituminous coal fields. Surface mapping can readily define the local joint system, and the mine can be developed to allow for joint weakness of the roof.

From a study of underground mining problems in Pennsylvania, McCulloch and others (Paper 6. *Geologic Investigations of Underground Mining Problems*) concluded that core logs on a grid system of not more than 3,000-foot centers and optimumly 2,000-foot centers are needed to obtain geologic information of the type necessary to define areas that pose problems for safe mining. They found that such a grid system was adequate to predict areas of probable roof instability and trends of sandstone channels. However, this was less successful for predicting trends of clay veins, which affect the liberation of methane gas during mining.

A number of significant geologic factors were observed in a study of deep mines by McCulloch and others (Paper 7. *Selected Geologic Factors Affecting Mining of the Pittsburgh Coalbed*). They concluded that coal-bed thickness is structurally controlled—it is generally thinner on anticlines and thicker in synclinal areas. Regional structural control of cleat is inferred because face cleat develops perpendicular to axial trends whereas butt cleat parallels axial trends. Clay veins tend to cluster along the axes of synclines and intersect to form cells that isolate methane gas. Differential pressures of up to 260 lb/in^2 exist between a mined area and an adjacent virgin cell. All of these factors are related and can be established during the early stages of mine development, providing there is sufficient density of core logs during the exploration program.

In summary, these papers demonstrate that specific geologic factors affect the safe mining of coal. Among the more salient factors applicable to mining of bituminous coal in Pennsylvania are:

1. Face and butt cleat develop perpendicular and parallel, respectively, to fold trends. The cleat forms an orthogonal joint system of consistent attitude over a large area. Face cleat trends WNW and butt cleat trends ENE.

2. Roof conditions in mines tend to be unstable when the workings parallel the joint (cleat) direction, but are more stable when the workings bisect the joint directions at a large angle.

3. Channel-fill sandstone bodies define areas of mining problems. Roof falls are associated with a zone of disrupted shales at the margins of the channel, and the sandstones are difficult to mine.

4. In the roof rock, small-scale channels, scours, and slickensides are sedimentary structures indicative of unstable conditions.

5. Where the interval to the next overlying coal is less than 30 feet and is composed of thin layers of limestone, shale, and sandstone, it may be designated as an area of unstable roof.

6. Liberation of large amounts of methane gas may occur during roof falls. High-pressure methane may develop in cells formed by intersecting clay veins that tend to cluster in synclines.

7. Optimum core drilling to recognize these geologic factors during mine exploration is on a grid spacing of 2,000 to 3,000 feet.

Underground mining of coal to achieve energy independence is inherently dangerous and expensive. Understanding of geological conditions in a mine is necessary to promote savings in terms of people and capital.

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Information Circular 75
1974

GEOLOGIC CAUSES AND POSSIBLE PREVENTIONS OF ROOF FALL IN ROOM-AND-PILLAR COAL MINES

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PREFACE

Today, we see a growing awareness in our nation of the importance of coal and foresee it playing a significant role in the solution of our energy crisis. The coal-mining process, therefore, becomes a vital link between this natural resource in the ground and the production of energy.

Coal recovery by mining has been hampered by certain technological problems, many of them solvable. The more data and information available, the easier it is to recognize and avoid problem areas entirely or to take the necessary steps toward reducing the problem to a minimum.

This report presents geologic information relating to the causes of shale roof falls, a major hazard in underground mining, and suggests ways to minimize this danger. The data have been gathered in active mining areas of Greene County, Pennsylvania; similar types of information and their application can be of great use in a wide variety of locations and situations.

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GEOLOGIC CAUSES AND POSSIBLE PREVENTIONS OF ROOF FALL IN ROOM-AND-PILLAR COAL MINES

by

Bion H. Kent

ABSTRACT

Severe and frequent roof falls of shale are the major hazard in underground mining in the room-and-pillar Pittsburgh coal mines of southwestern Pennsylvania. Several structural and sedimentary features directly affecting shale roof stability have been identified by core drilling, geologic mapping, and mapping roof falls in an area of active underground mining in eastern Greene County, Pennsylvania.

Mine maps of roof falls show two patterns: (1) **unidirectional**, in which roof falls are confined to passageways parallel to the northeast-trending butt cleat in Pittsburgh coal, and (2) **bidirectional**, in which roof falls show no preferred orientation with respect to passageway or cleat directions. Unidirectional roof falls are clearly related to northeast-trending sets of tension or release-type joints in the shale roof and overburden rocks. Bidirectional roof falls occur in zones of disrupted shale that are marginal to the edges of thick lenses of channel-fill sandstone overlying the coal; this type of shale roof is much weaker and much more difficult to control. The marginal zones are as much as several miles long, but their maximum width is about 500 feet.

Significant reductions in the incidence of unidirectional roof fall have been noted after mine haulageways and workings were turned oblique to the northeast-trending set of joints. The incidence of bidirectional roof fall may be reduced by crossing the marginal zones at right angles and by leaving longitudinal pillars to support the roof in the marginal zones.

INTRODUCTION

Roof falls of shale are the major hazard in room-and-pillar coal mines of southwestern Pennsylvania. Many published and unpublished investigations have been made and roof falls have been attributed to a variety of causes; but to date, there are no satisfactory explanations why roof falls occur in some areas of shale roof and not in others. This suggests that the geologic causes are complex and that important geologic factors have been overlooked.

In eastern Greene County, southwestern Pennsylvania (Plate 1), the Pittsburgh coal bed is 400-600 feet below the level of surface drainage. Mining has been very extensive in this area. More than 500 exploratory holes have been drilled to the base of the Pittsburgh coal, and the surface geology has been mapped in detail at a scale of 1:24,000 (Kent, 1969, 1971, 1973; Roen, 1970, 1973). The volume of information accumulated on sedimentary and structural features of rocks overlying the Pittsburgh coal is perhaps larger in this area than in most parts of the State, and much of this information is relevant to study of the problem of roof falls.

Roof falls in mines in Greene County show two distinct patterns: (1) In some mine areas where shale directly overlies the Pittsburgh coal, nearly all roof falls occur along northeast-trending mine passageways parallel to the butt cleat direction in the coal. Roof falls showing this linear pattern are here termed *unidirectional* roof falls. (2) In other mine areas where shale overlies the coal, but where thick sandstone lenses are known to overlie the coal nearby, the severe and frequent roof falls that occur in the shale roof have no uniform orientation relative to cleat or passageways. Roof falls showing this pattern are here termed *bidirectional* roof falls. In the places where both factors are present, their effects cannot be clearly separated.

The purpose of this report is to outline probable cause and effect relationships (unidirectional roof fall is related primarily to joints, and bidirectional roof fall is related primarily to the presence nearby of sandstone channel deposits in rocks overlying the Pittsburgh coal), and to report steps taken which have minimized rock falls attributed to these causes.

ACKNOWLEDGEMENTS

The author is indebted to the late Thomas A. King and other officers of the U.S. Steel Corporation, and to J.M. Vonfeld, Exploration Manager, Consolidation Coal Company, for use of core-log data in the area of this geologic study. He is also grateful to Roger C. Parsons, Senior Research Engineer, Continental Oil Company, who gave freely of his knowledge concerning the geologic aspects of the roof-fall problem in a mine south of the area of this study.

STRATIGRAPHY

INTRODUCTION

In this study, attention was given exclusively to the sequence of beds between the base of the Pittsburgh coal and the base of the overlying

Sewickley coal. According to the stratigraphic nomenclature for Upper Pennsylvanian and Lower Permian rocks in southwestern Pennsylvania, as revised by Berryhill and Swanson (1962), this sequence of beds includes the following members of the Pittsburgh Formation: the Lower Member (from the base of the Pittsburgh coal to the base of the Redstone coal), the Redstone Member (from the base of the Redstone coal to the base of the Fishpot coal), and the Fishpot Member (from the base of the Fishpot coal to the base of the Sewickley coal).

Throughout this report, repeated references are made to the informal term "Pittsburgh sandstone." The name Pittsburgh sandstone, as used by Piper (1933), is widely applied in local usage throughout southwestern Pennsylvania to identify a massive sandstone unit, in part consisting of sandstone-filled channels, which occurs just above the Pittsburgh coal bed. In the revised stratigraphic nomenclature of Berryhill and Swanson (1962) this unit is identified as a sandstone in the Lower Member of the Pittsburgh Formation. However, in places the Redstone coal has been scoured out and later filled in by sandstones, and some thicker sandstones also fill scours cutting out the Fishpot coal. Under some circumstances, formal stratigraphic nomenclature is difficult to apply. The lower parts of such channel-fill sandstones may be said to represent the Lower Member of the Pittsburgh Formation, and the middle and (or) upper parts may represent the Redstone and (or) Fishpot Members, but the members cannot be separated nor can they be defined. To further complicate the problem, it is likely that the channel-fill sandstone that rests on the Pittsburgh coal is younger than the adjoining rocks of the Lower Member and the Redstone Member and perhaps even part of the Fishpot Member.

GENERAL FEATURES

Throughout the area (Plate 1) the Sewickley coal is a persistent bed about 120 feet above the Pittsburgh coal. Variations in the interval between the two beds are shown in Figure 1A. The upper third of the interval consists mainly of limestone; the middle third consists of shale and limestone; and the lower third consists either of shale and limestone or of thick lenses of the Pittsburgh sandstone which locally may make up most of the sequence between the two coals.

Consequently, the greatest lateral contrast in rock types in the interval occurs in the lower third where layers of shale and limestone grade abruptly into or terminate abruptly against thick lenses of the Pittsburgh sandstone. These three disparate rock types form the roof rock of the Pittsburgh coal bed.

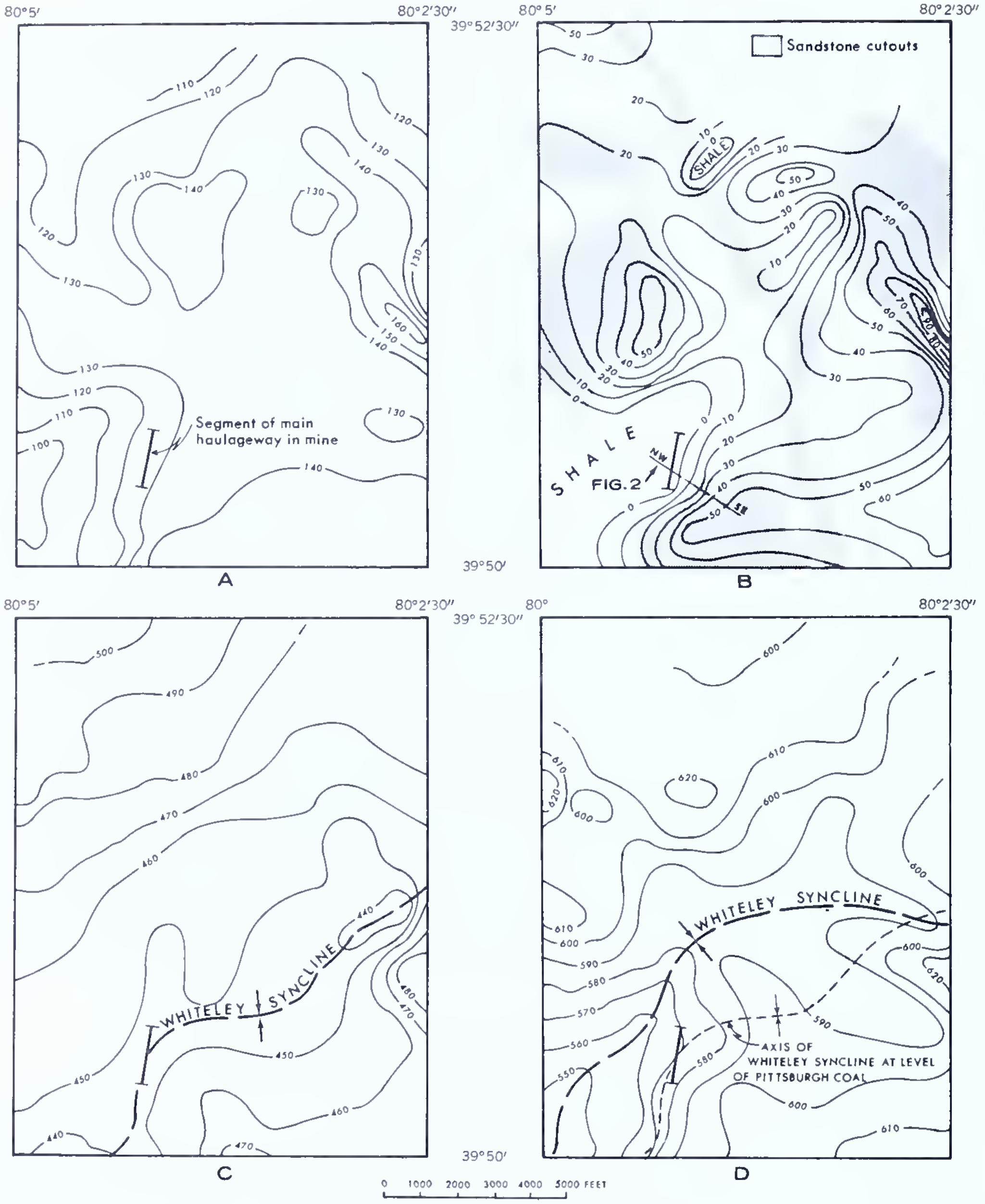

Figure 1. Subsurface sedimentary and structural features in the sequence of rocks between the Pittsburgh and Sewickley coal beds in the north-central part of the Garards Fort quadrangle, southeastern Greene County (see Plate 1). Contour interval, 10 feet; datum is mean sea level. A. Isopach map of interval from base of Pittsburgh coal to base of overlying Sewickley coal. B. Isopach map of Pittsburgh sandstone (as used by Piper, 1933). C. Structure contour map, base of Pittsburgh coal. D. Structure contour map, base of Sewickley coal.

PITTSBURGH SANDSTONE

Distribution

The Pittsburgh sandstone as used by Piper (1933) extends in a northwest-trending belt 4-6 miles wide from Monongalia County, West Virginia, into southeastern Greene County, Pennsylvania. The part of the belt shown in Figure 1 directly overlies the Pittsburgh coal. Outside of this Pittsburgh sandstone belt, the sequence of rocks between the Pittsburgh coal and the overlying Sewickley coal consists of shale intercalated with beds of limestone.

The Pittsburgh sandstone ranges in thickness from a featheredge to as much as 80 feet. The thicker deposits, typically about 60 feet thick, are lens shaped with irregular bases. Many of the lenses are separated from the underlying coal by as much as 30 feet of shale, and others cut into or through the Pittsburgh coal. Laterally, many lenses terminate abruptly against shale, but a few thin gradually to extinction in shale. At a few places in the Pittsburgh sandstone belt the sandstone is absent.

Pattern of Deposition

The lower part of the Pittsburgh sandstone was deposited in a complex system of braided stream channels developed at different times following deposition of (Pittsburgh) peat. Some of the channels were completely filled with sand, and, as the influx continued in places, the sand spread out over the surrounding area as a sheetlike deposit (Figure 3).

The number of anastomosing sandstone-filled channels composing the lower part of the Pittsburgh sandstone could not be determined at most places, because the widths of the channels are generally less than the spacing of exploratory drill holes. Underground mine workings are also rather widely spaced, and mine maps of these workings indicate only where sandstone cutouts were encountered. Consequently, only those sandstone-filled channels that cut out some or all of the underlying Pittsburg coal beds are shown in Plate 1, and there is only an incomplete record of sandstone-filled channels that rest on or are just above the coal bed. Isopachs showing the thickness of the Pittsburgh sandstone (Plate 1) were spaced evenly between core-hole data points, in accordance with the common method of preparing isopach maps from point control; however, this method tends to smooth out abrupt irregularities in sandstone thickness, to obscure small channels, and to mask any abrupt terminations of sandstone against shale.

In the small area of Figure 1B, the Pittsburgh coal has been mined extensively, and exploratory drill holes were more closely spaced than in the larger area of Plate 1. Consequently, the variations in thicknesses of channel-fill sandstone and the terminations of sandstone against shale are more accurately delineated on Figure 1B. The distribution of sandstone cutouts (Figure 1B) suggests the braided pattern that is believed to characterize the Pittsburgh sandstone deposits throughout the entire sandstone belt.

Compaction Effects on Interval Thickness

The amount of compaction that took place in the sequence of rocks between the base of the Pittsburgh coal and the base of the Sewickley coal is indicated by the experimental data in Table 1. Experimental data on the compactability of carbonates is unavailable, but the limestone beds are generally very argillaceous and the compactability of a "clayey lime" might be similar to that of a clay or mud.

Table 1. Average Compactability, in Percent Reduction of Original Bulk Volume, of Different Types of Sediment at Different Depths of Burial

From Athy (1930), Raistrick and Marshall (1939), Weller (1959)

Sediment type		Depth of burial (in ft.), and corresponding percent reduction					Rock type after compaction
	0-50	1,000	2,000	3,000	4,000	5,000	
Clay	—	20	35	40	—	—	Claystone.
Mud	—	25	35	41	46	50	Mudstone or shale.
Mud	0-23	31	36	—	—	45	Mudstone or shale.
Peat	80	90	95	—	—	—	Coal.
Sand	11	—	—	—	—	13[1]	Sandstone.

[1] Calculated from data given by Athy (1930) and Weller (1959).

The original overburden on the Pittsburgh coal in eastern Greene County was at least 2,000 feet. At that depth, as shown in Table 1, the bulk volume and, therefore, the thickness of clay and mud is reduced an average of 35 percent in the transformation to claystone, mudstone, and shale; that of peat is reduced 95 percent in the transformation to coal; and that of sand is reduced only about 11 percent in the transformation to sandstone. Table 1 also indicates that clay and mud continue to compact as overburden thickness increases, whereas peat and sand reach near-maximum compaction during initial stages of burial.

Because the compaction ratio from mud to shale is greater than the ratio from sand to sandstone, the interval between the base of the Pittsburgh coal and the base of the Sewickley coal tends to be smaller in areas where the Pittsburgh sandstone is thin or absent. This relation can be demonstrated in a general way by comparing Figures 1A and 1B.

At a few places, typified by locality X (Plate 1), an unusually thick sandstone sequence characterizes an unusually thin Pittsburgh to Sewickley coal interval. This anomalous relation might be explained if, following the original deposition of mud, a deep channel was eroded into the semi-consolidated sediment and only partly filled with sand. The Sewickley peat was subsequently deposited in the depressions left by the partly filled channel.

Where the recorded thickness of Pittsburgh sandstone is on the order of 50 feet, where the base of this sandstone unit is near the top of the underlying (Pittsburgh) coal bed, and where the Pittsburgh to Sewickley coal interval is less than 140 feet, it may be presumed that the form of the sandstone is chiefly that of a channel-fill deposit rather than that of a more uniformly distributed sheetlike deposit.

Compaction Effects on Marginal Zones

The effects of overburden and differential compaction are marked along the margins of sandstone-filled channels of Pittsburgh sandstone. During compaction, individual layers of claystone and mudstone are bent, stretched, and even broken around the relatively unyielding lenses of sandstone. These effects decrease away from the margins of sandstone-filled channels. The result of these effects is particularly well illustrated in a segment of a haulageway, the location of which is shown in Figure 1. The segment is about 200 feet northwest of the edge of a thick sandstone channel (see Figure 1B). Along this segment, shale roof is exposed by numerous roof falls, and the individual layers of claystone and mudstone that compose the roof are extensively buckled, contorted, fractured and sheared.

Marginal zones of deformed shale layers are as much as several miles long (see Plate 1). They are estimated to be from a few feet to about 500 feet wide depending on the thickness of the sandstone lens and the abruptness with which the sandstone lenses out in the enclosing shale. The sandstone-filled channels are sinuous in plan view, and they change in width and orientation accordingly. However, no significant distortion and crushing of shale would occur in areas where sandstone grades gradually into shale.

Some of the deformation of shale in marginal zones may have been produced by stresses that originated from lateral compression during folding. A sandstone lens in a matrix of less rigid shale under stress can be thought of as analogous to an object such as a steel bar in a slab of concrete under stress. A crude estimation of the effectiveness of stress differentials beyond the sandstone margins, and of the effective width of a marginal zone, can be derived from such studies as those of Goodier (1933); he concluded (p. 39) that at a distance of some four diameters

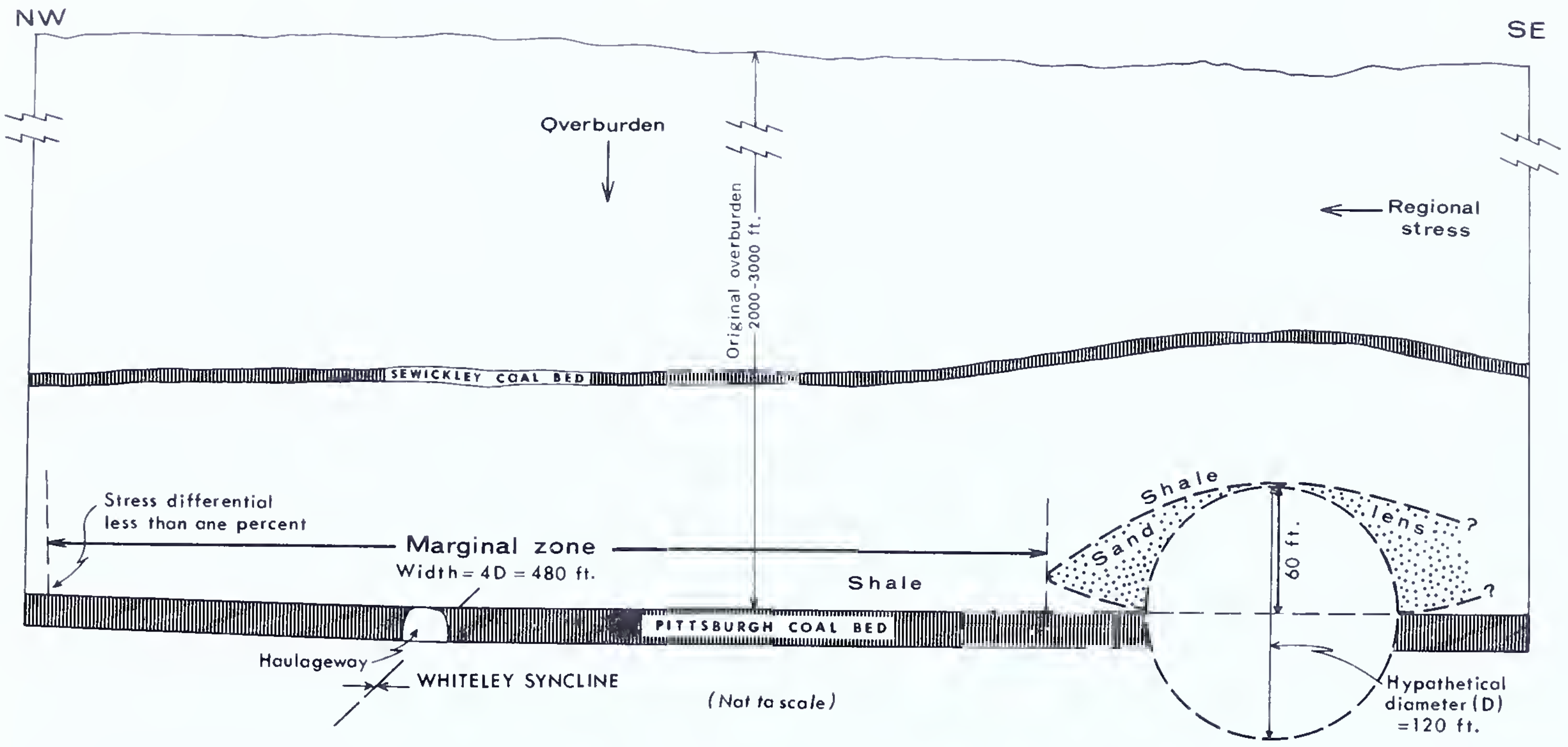

Figure 2. Diagrammatic section along line in Figure 1B showing position of mine haulageway with respect to sandstone lens to the southeast, and calculated width of marginal zone of disturbed shale.

from an inclusion such as a reinforcing rod in cement under stress, the stress distribution, which would be uniform without the inclusion, would be modified by no more than 1 percent. A lens of channel-fill sandstone that has a maximum thickness of about 60 feet can be considered to act as a rigid hemispherical body with a diameter of about 120 feet (Figure 2). By analogy with Goodier's (1933) reinforcing rod, the maximum width of the zone over which the stress differential would drop to 1 percent is four times the diameter of the hemisphere, which is eight times the thickness of the lens, or about 480 feet.

Accordingly, widths of marginal zones are scaled in at about 500 feet on Plate 1 inasmuch as the isopachs of Pittsburgh sandstone indicate a maximum thickness of about 60 feet. However, because the rule of thumb expressed by the 8:1 ratio applies only to lenses of channel-fill sandstone that thin abruptly at their margins, a width of 500 feet is about the maximum to be expected.

STRUCTURE

Eastern Greene County lies just to the east of the major axis of the Appalachian basin synclinorium. The regional dip of the rocks is generally less than 1°, and slightly more in a few local areas. In the area shown on Plate 1 the amplitude of the Bellevernon anticline is about 300 feet and that of the Fayette anticline, to the southeast, is about 650 feet.

FOLDS

The Bellevernon anticline, the Fayette anticline, and the intervening Whiteley syncline trend about N40E across the area. Structural dips on the flanks of these anticlines generally are less than 1° although some dips, probably reflecting the effects of differential compaction, locally exceed 5°.

As illustrated by Figures 1C and 1D, the trends of the fold axes are markedly sinuous in detail, and fold axes in different coal beds or other horizons do not precisely correspond due to unsystematic changes in the thickness of intervals between beds (Figure 1A). The effects of differential compaction and of irregularities on the surface of deposition of the coal, which are superimposed on the broad-scale tectonic folds, combine to produce many minor irregularities in the structure contours (Figures 1C and 1D).

During folding, the thick lenses of Pittsburgh sandstone must have resisted compressive forces (from the southeast) more strongly than the enclosing shale. Resulting differential movements may have additionally crushed and distorted shale adjoining the sandstone buttresses. Any such crushing and distortion would have been most intense in the shale along the northwest and southeast sides of sandstone lenses, which were the sides perpendicular to the direction of compressive force.

FAULTS

Faults are relatively rare in the rocks of southwestern Pennsylvania. In the area shown on Plate 1, almost all of the few faults that have been observed strike parallel to fold axes and fault planes commonly dip toward the axes of synclines; reverse faulting is most common and displacements are generally less than 5 feet. The orientation of these faults and relative movements suggest a wedging action resulting from, and contemporaneous with, folding.

The only fault shown on Plate 1 is an exception to the general rule. It is a strike-slip, left-lateral fault zone extending for a distance of several miles in the Carmichaels quadrangle. This fault strikes about N55W, in the direction of the Set B joints of Nickelsen and Hough (1967, Plate 3) and within the northwest section of joint trends noted in the area shown in Plate 1. The rocks on the northeast side of this fault seem to have moved to the northwest relative to those on the southwest side, as suggested by apparent displacements of the Brownsville anticline and the Whiteley-Port Royal syncline.

JOINTS AND CLEAT

Regional Pattern

Trends of major joint sets in southern New York State and northern Pennsylvania (the northern part of the Appalachian basin) were determined by Parker (1942), and major joint sets in western Pennsylvania by Nickelsen and Hough (1967).

Parker (1942) showed that a double set of joints intersected at angles of 10°-30° (Set I), and had a mean strike trending approximately perpendicular to fold axes; and that a single set of joints intersected the mean strike of the double set at approximate right angles (Set II) and trended approximately parallel to fold axes. Parker (1942, p. 395-396) described Set I joints as remarkably planar, and interpreted them to be the result of shearing stresses. He (Parker, 1942, p. 396-397) described Set II joints as curved and irregular, having a rough, torn appearance, and attributed them to tensional stresses.

Nickelsen and Hough (1967, Plate 3) described and mapped three major sets of joints (B, C, and "I") in the coal-bearing rocks of southwestern Pennsylvania. In their nomenclature, Set B joints (in shale) strike about N55W; Set C joints (in shale) strike about N80W; and Set "I" joints (the face cleat in coal) strike about N70W. The trend of Sets B, C, and "I" joints is approximately perpendicular to fold axes. Nickelsen and Hough (1967, p. 613) stated that joints belonging to Sets B, C, and "I" conform descriptively to the planar Set I joints of Parker (1942), but they preferred to call them "systematic" joints. They also noted joints belonging to sets which intersect Sets B, C, and "I" at approximate right angles, which they called "nonsystematic." These sets of nonsystematic joints conform to the nonplanar Set II joints of Parker (and include the butt cleat in coal). Intersecting sets of systematic and nonsystematic joints are shown diagrammatically on Plate 1, where, for convenience, sets of nonsystematic joints are called Sets B′, C′, and I′.

Greene County Pattern

In the area shown on Plate 1, two major sets of joints in shale, sandstone, and limestone were measured during the present work: (1) a northwest-trending set oriented in the N55-85W sector; and (2) a northeast-trending set oriented in the N5-35E sector. Joints belonging to the northwest-trending set correspond to the systematic joints of Nickelsen and Hough (1967) and include their Sets B and C, and those belonging to the northeast-trending set correspond to their nonsystematic joints.

In both outcrops and mines the face cleat of the Pittsburgh coal is oriented in the N70-75W sector and the butt cleat is oriented in the N15-20E sector. These well-defined cleat directions correspond very well with directions observed regionally by Nickelsen and Hough (1967); and the narrow ranges of directions fall within the wider ranges of directions of joints in shale, sandstone and limestone.

The northwest-trending joints and the face cleats commonly are planar, smooth, parallel to each other, closely spaced, and crosscut other joint sets; whereas the northeast-trending joints and the butt cleats commonly are jagged, rough, curving, offset by other joint sets, and more widely spaced. Many of the northeast-trending joints terminate against joints of the more regular northwest-trending sets, and many curve abruptly and terminate against adjacent joints of the same northeast-trending set.

Origin and Age

The origin and age of joints and cleats have been discussed by Raistrick and Marshall (1939, p. 42-45), Parker (1942), Hubbert and Rubey (1959, p. 152-153), Hodgson (1961), Secor (1965), and Nickelsen and Hough (1967), among others.

The factors that seem most relevant to the association of joints and cleats with the roof-fall problem in Greene County are as follows:

(1) Vertical joints normal to bedding were formed very early in the diagenesis of the sediments.

(2) Sediments of the Appalachian basin were subjected to directional tectonic stress penecontemporaneously with diagenesis. This stress contributed to the development of fractures, and established regional direction patterns.

(3) Although affected by compressive stress, any or all joints may be tension- or release-type fractures. Joints approximately parallel to fold axes are almost certainly tension fractures.

(4) Concepts of origin adequately explain well-developed tension fractures at substantial depths in all coal basins.

(5) The face cleat in coal is most sensitive to, and indicative of, directional compressive stress.

(6) Cleats and joints form sequentially as follows: cleats in coal; joints in shale; joints in sandstone.

(7) The spacing of joints varies with rock type as follows: (a) cleats in coal are very closely spaced and well developed; (b) joints in shale are generally less than 1 foot apart, and are not so well developed as cleats in coal or as joints in limestone and sandstone; (c) joints in limestone are about 1 foot apart and are well developed; and (d) joints in sandstone are typically more than 1 foot apart and are well developed.

(8) The orientation and spacing of joints and cleats apparently do not change in the depth range available for observation, although the joints at depth may be tightly closed by the confining pressure.

THE ROOF-FALL PROBLEM

UNIDIRECTIONAL

Shale roof falls were prevalent along mine passageways oriented northeast, parallel to the butt cleat in a Pittsburgh coal mine that is about 10 miles north of the study area (J. Kepenich, oral commun., 1968). Roof falls along mine passageways oriented northeast were also prevalent in a Sewickley coal mine in the southeastern part of the area shown on Plate 1. Shale roof falls also occur frequently in a Pittsburgh coal mine southwest of the Pittsburgh sandstone belt (Plate 1); more than 90 percent of the roof falls mapped in that mine occurred along mine passageways oriented northeast, parallel to the butt cleat in the coal (R.C. Parsons, oral commun., 1969-1971). Roof falls occurring in a linear pattern along this northeast direction are referred to here as unidirectional.

The prevalence of unidirectional roof fall parallel to northeast-trending sets of joints is presumptive evidence that the joint sets create zones of weakness in the shale roof. Incipient northeast-trending tension fractures in the shale roof tend to open when stress is relieved during mining, and haulageways driven parallel to that principal direction of jointing are particularly exposed to a high incidence of roof fall.

BIDIRECTIONAL

Representative areas of frequent roof fall in the mine in southeastern Greene County are shown on Plate 1; the pattern of roof fall in these areas is bidirectional, having no uniform orientation relative to cleat or passageways. The mine roof in these areas is slumped, buckled, contorted, fractured, and sheared shale, and most of the areas are marginal to thick lenses of Pittsburgh sandstone.

Localities A and B, Plate 1, are segments of a marginal zone. The haulageway shown on Figure 1 is within this segment, and is estimated to be about 200 feet northwest of the edge of an abruptly terminating lens of channel-fill Pittsburgh sandstone (Figure 1B). The shale roof at locality A is along the northwest side of a thick sandstone buttress, and crushing of the shale roof may have been intense. (See discussion under "Folds.")

At locality C, Plate 1, the shale roof is highly contorted and structurally weak. Examination of the distribution of the Pittsburgh sandstone shows that the locality is surrounded by thick lenses of channel-fill sandstone that terminate abruptly in the shale, and that the area of roof shale is about 500 feet wide and 1,000 feet long. In this area, effects of differential compaction and crushing were at a maximum, and stress differentials decreasing away from the margin of one sandstone body would be reinforced by stress differentials increasing toward the margin of another. The combined effects are dramatically apparent, in that the highest incidence of roof falls was reported at this place in the mine.

At localities D and E (Plate 1), the mine workings were under shale roof, but the shale roof remained firm and roof falls were uncommon. Both of those localities are well outside the calculated 500-foot-wide marginal zone and, therefore, it is unlikely that the shale roof was appreciably affected by differential compaction, or that significant stress differentials developed.

Some geologic relations at locality Y (Plate 1) are shown in Figure 3. At this locality the roof rock over former underground mine workings in the Pittsburgh coal bed is exposed in cross section in the highwall of an abandoned strip mine, and the geologic relations are unusually plain. When this area was mined underground, a major roof fall occurred. A lens of channel-fill Pittsburgh sandstone directly overlies the Pittsburgh coal (Figure 3) and terminates abruptly against shale about 50 feet to one side of the mine entry. An adjoining marginal zone of contorted shale

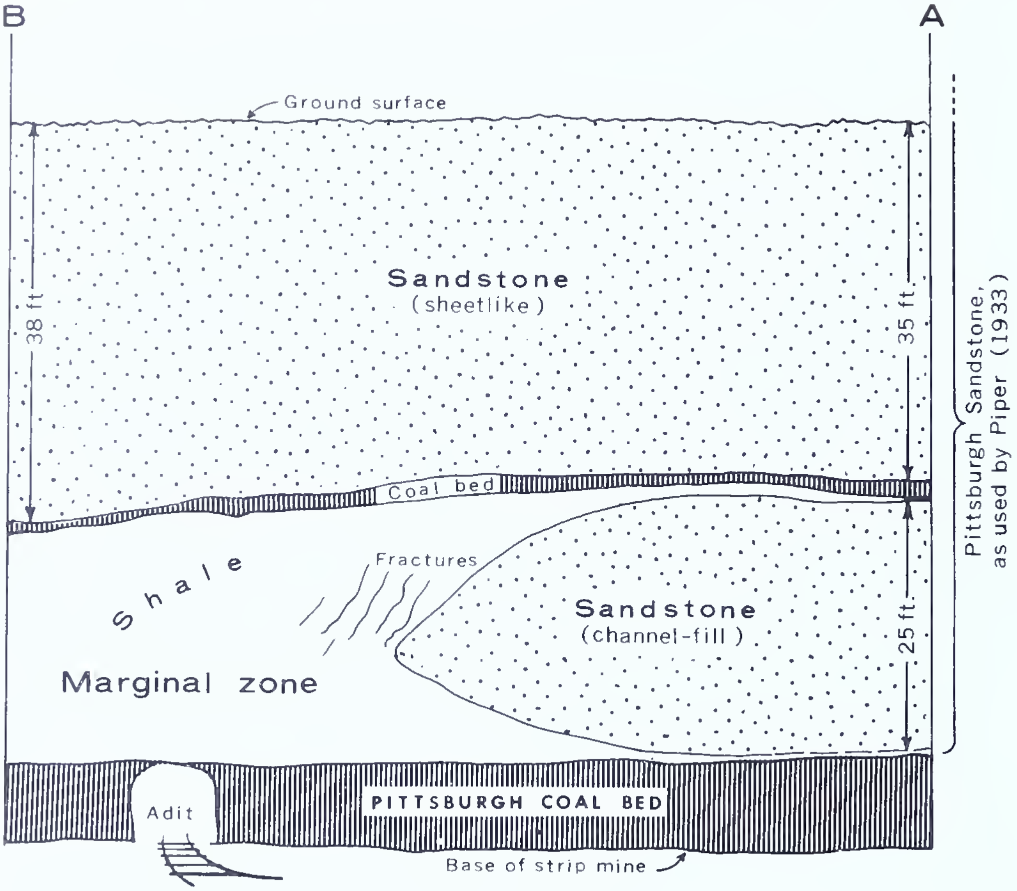

Figure 3. Geologic relations at field locality Y, south-central part of the Masontown quadrangle (see Plate 1). Sketch shows that the Pittsburgh sandstone, as used by Piper (1933), is composed of two sandstone units exposed in a northwest-facing highwall of a combination strip and underground mine in the Pittsburgh coal. When this area was part of an underground mine a major roof fall occurred in the adit.

extends outward from the channel-fill sandstone margin and over the mine adit.

Some areas of bad roof beneath a thick cover of Pittsburgh sandstone are indicated on Plate 1, in apparent contradiction to the general rule that such areas are safe. In some of these areas the Pittsburgh sandstone is believed to be a composite unit similar to that shown in Figure 3 where the lower part consists of channel-fill deposits and the upper part consists of sheetlike deposits. In isopach studies of the composite unit of Pittsburgh sandstone, thick sheetlike deposits of the upper part tend to mask locations of underlying channel-fill deposits and accompanying marginal zones of shale (Figure 3).

CONTROL OF ROOF FALL

The roof-fall hazard can be anticipated and minimized, in part, by proper orientation of mine workings on the basis of surface and subsurface mapping of structural and sedimentary features in the rocks that overlie the coal.

The incidence of unidirectional roof fall can be reduced if mine workings are oriented to bisect the angles formed by intersecting sets of major joints. In southwestern Pennsylvania a simple practical way to determine the optimum directions of mining to minimize roof-fall problems associated with joints is to bisect the angles formed by the intersecting face and butt cleats in the coal being mined. On this basis, optimum orientations of mine workings in southeastern Greene County are N30W and N60E.

Northeast-trending joints are everywhere present in southwestern Pennsylvania, but the degree to which northeast-trending tension fractures in the shale roof may be opened by stresses relieved during mining will vary from place to place. Consequently, the effectiveness of reorienting mine workings for the purpose of introducing partial control of unidirectional roof fall must be evaluated on the basis of an overall, long-term reduction in the incidence of roof falls. For example, mining directions in the Sewickley coal mine (Plate 1) were reoriented (1967-68) to about 45° from face and butt cleat directions in Sewickley coal; and mining directions in a Pittsburgh coal mine about 10 miles north of the study area were reoriented (1969) to about 45° from face and butt cleat directions in Pittsburgh coal. To date (1972) significant reductions in the incidence of roof falls have been noted in both of those mines.

Bidirectional roof fall is more difficult to control. Main haulageways should be located outside of potentially hazardous marginal zones, but where marginal zones cannot be avoided, haulageways and mine workings should cross them at right angles, and longitudinal pillars and other supports should be amply provided. Long-term use of mine workings in marginal zones and long-term mining within a marginal zone and parallel to its trend should be avoided.

Marginal zones are localized and are difficult to find in advance of mining. In areas where thick sandstone cover on coal is suspected, extensive exploratory drilling will provide additional information on the locations of channel-fill sandstones, and mine maps of sandstone cutouts provide data on the trends of sandstone-filled channels which will help predict their positions in unmined areas. As roof bolts are installed during mining beneath a sandstone lens that rests directly on the coal, identification of the lithologies (sandstone versus shale) encountered in drilling for roof bolt emplacement may record a rise in the base of the overlying sandstone lens, which could warn of a possible marginal zone ahead.

Regional maps of the trends of sandstone-filled channels and sandstone belts establish the general pattern of the ancient channel system. Isopach maps of the interval between the top of the coal bed and the base of the first overlying sandstone would provide a better way to establish the existence and location of some marginal zones.

CONCLUSIONS

The distribution and frequency of roof fall in room-and-pillar coal mines in southwestern Pennsylvania can be related to structural and sedimentary features in rocks overlying the coal.

Unidirectional roof fall occurs along northeast-trending sets of tension joints in the shale roof over the coal. Unidirectional roof fall has been minimized by orienting mine workings about 45° from face and butt cleat directions in the coal.

Bidirectional roof fall occurs most commonly in zones of distorted shale on the margins of thick lenses of channel-fill sandstone. The distortion is a result of the markedly greater compactability of clay and mud compared to that of sand. As the sediments were differentially compacted, individual layers of shale were bent, stretched, and even broken around relatively unyielding lenses of sand, especially on the margins of sandstone-filled channels, where the compaction differential is greatest. Many of these marginal zones can be found by careful study of data obtained during development drilling and mining. The incidence of bidirectional roof fall may be reduced by orienting mine workings to cross marginal zones at right angles, and by leaving longitudinal pillars to support the roof in the marginal zones.

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PENNSYLVANIA GEOLOGY is published bimonthly by the Topographic and Geologic Survey, Main Capitol Annex, Harrisburg, Pennsylvania, 17120.

OCTOBER 1971

CHANNEL SANDSTONES IN COAL

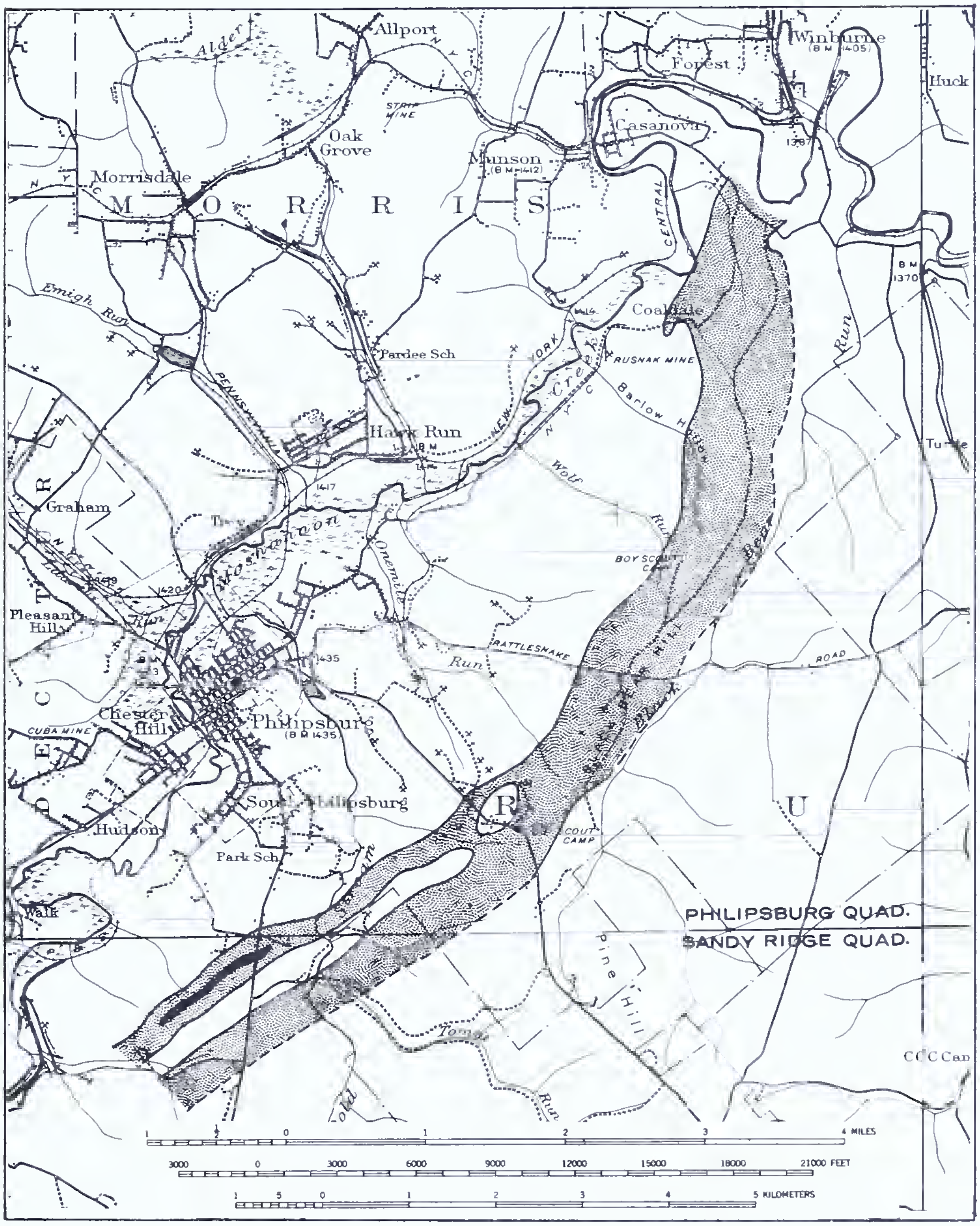
Fluvial sandstones, variously called channel or shoestring sandstones, are quite common in the bituminous coal measures of Pennsylvania. The Kittanning sandstone in a portion of Centre County, provides an excellent example of the basic geometry and behavior of one of these fluvial sandstone units. Geologic mapping of the Philipsburg 7½-minute quadrangle showed that there were enough surface exposures of the Kittanning sandstone to delimit its occurrence and trend in that area.

As the Kittanning sandstone overlies the Clarion coal, the technique used to outline the boundaries of the sandstone required only identification of the rock type immediately overlying the Clarion coal (roof rock). This was done wherever it was exposed in road cuts or strip mines. The stipled pattern on the accompanying map represents that area where the Clarion coal seam is directly overlain by the Kittanning sandstone. Solid colored areas are where the sandstone channel has cut out the coal. Clear white areas east and west of the stipled pattern and at places within it, indicate where the sandstone gradually rises up to 30 feet above the coal. In these white zones, shale occupies the interval between the sandstone and the coal. This shale roof rock thickens rapidly at first then gradually with greater distance from the stipled area at the expense of the Kittanning sandstone which rises and thins as the shale thickens. The extension of this sandstone's occurrence into the Sandy Ridge 7½-minute quadrangle is based on drill hole information supplied by Rushton Coal Mining Company, Inc. which operates the Rushton mine on the Clarion coal in this area.

This narrow, sinuous, northeast-southwest trending sandstone is the remnant of an ancient southerly flowing river through this region. During the process of erosion, this stream cut a 30 to 50 foot deep, relatively flat-bottomed valley into the shales that normally overlie the Clarion seam. The width of the valley ranged from 0.5 miles to 0.8 miles across although in the Sandy Ridge 7½-minute quadrangle, it bifurcated into two narrower channelways that left a shale island between them. The sandstone is known to continue its general trend to the southwest into the Houtzdale 7½-minute quadrangle while its northeastern continuation is less clear but nonetheless predictable.

As this river matured, it deposited sands and gravels in its original valley in place of the eroded sediments. The Kittanning sandstone is the consolidated remnants of those sand and gravel deposits. Its three-dimensional shape reflects the original position and cross-section of the ancient river valley. The outside edges of the stipled area approximate the position of the valley walls.

In the Rushton mine, the main channel of the stream occasionally cuts through the Clarion coal and into the older underlying rocks (solid colored area on map). The width of the cut-out ranged between 100 and 300 feet. Similar



cut-outs of the coal can be expected to occur at other points along the course of the stream. Since the sandstone now fills the ancient river valley from bank to bank, it obviously occupies the original position of the Clarion seam in these cut-outs. The coal is, of course, present at or near the same level on both sides of such a "rock fault".

"Rock Faults" are not uncommon in the mining history of the area or for that matter in Pennsylvania's coal measures in general. Since mechanical mining equipment is not designed to cut through these hard sandstone bodies, the cut-outs pose an especially formidable obstacle to modern underground coal mining. This mechanical equipment is often seriously damaged by impact with unsuspected sandstones of this type. Additionally, costly rock headings (tunnels) often must be driven through the sandstone to reach coal acreage on the other side of a cut-out. Even when a channel sandstone merely overlies a coal seam, it is quite likely to produce adverse roof and water conditions.

Although the fluvial-type sandstone is common, it is not the only type of sandstone unit that occurs in the coal measures. Many sandstones do not occupy old river channels and consequently are not found to replace or cut-out the coal seams as in the above example. A fluvial-type sandstone must be identified as such, whenever possible, so that its potential effects on mining can be anticipated and so that predictions of its course through adjacent properties can be made. Only when the position of such a sandstone body is known in advance can a mine be laid out to minimize the sandstone's effect on the mine's operation and development.

Gary B. Glass

Report of Investigations 8230

Roof Rock Structures and Related Roof Support Problems in the Pittsburgh Coalbed of Southwestern Pennsylvania

By Noel N. Moebs

March 3 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

This publication has been cataloged as follows:

Moebs, Noel N

Roof rock structures and related roof support problems in the Pittsburgh coalbed of southwestern Pennsylvania / by Noel N. Moebs. [Washington] : Bureau of Mines, 1977.

30 p. : ill., maps ; 26 cm. (Report of investigations - Bureau of Mines ; 8230)

Bibliographic footnotes.

1. Coal - Geology - Pennsylvania - Pittsburgh coalbed. 2. Mine timbering. 3. Mine roof bolting. I. United States. Bureau of Mines. II. Title. III. Series: United States. Bureau of Mines. Report of investigations - Bureau of Mines ; 8230.

TN23.U7 no. 8230 622.06173

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ROOF ROCK STRUCTURES AND RELATED ROOF SUPPORT PROBLEMS IN THE PITTSBURGH COALBED OF SOUTHWESTERN PENNSYLVANIA

by

Noel N. Moebs [1]

ABSTRACT

The Bureau of Mines investigated severe coal mine roof support problems along a section of main entries in the Pittsburgh coalbed in southwestern Pennsylvania to identify the causative factors. The mine roof was examined in detail, and various sedimentary structures are described that contributed directly to irregular and unstable roof. Small-scale paleochannels, scours, and related slickensides were identified as the leading cause of bad roof, and isopach maps were prepared to illustrate a method whereby the presence of these structures could be inferred in advance of mining. Probably second in importance was the occurrence of relatively incompetent flaggy, poorly cemented sandstone, weakened by coal and micaceous laminea. No effect of in situ stresses on roof stability was detected.

INTRODUCTION

The Bureau of Mines has been investigating coal mine roof instability since 1910[2] and has issued many publications on improving methods of roof support.[3] In addition, since 1973 the Technical Support Group of the Mining Enforcement and Safety Administration has provided technical assistance for particular roof problems. However, the factor of geologic variables and their bearing on roof falls has not been fully appreciated until recently, and techniques for identifying and analyzing these variables are only now emerging.

The Bureau is attempting to identify and assess geologic features commonly associated with roof failure and select those that constitute the most important causative factors in roof falls. These features should have the greatest potential for application to the study, explanation, and prediction of coal mine roof failure. Nearly all roof failures can be attributed to two chief causes: (1) the existence of excessive stresses that exceed the breaking strength of the rock strata comprising the roof of the mine entry and (2) the inability of the roof rock strata to support their own weight or that of the immediate overlying rock. Some roof failure is facilitated by the action of humid mine air, which softens claystone roof rock and leads to loss of bolt tension or progressive deterioration by slaking.

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[2] Greenwald, H. P., E. R. Maize, I. Hartmann, and G. S. Rice. Studies of Roof Movement in Coal Mines. 1. Montour 10 Mine of the Pittsburgh Coal Co. BuMines RI 3355, 1937, 41 pp.

[3] See index of "List of Publications Issued by the Bureau of Mines From July 1, 1910, to January 1, 1960" and succeeding annual and 5-year listings.

Methods of research for determining the in situ stress in heterogeneous stratified rock are slow, complex, and unreliable, and practical applications of stress analysis to coal mine roof problems are severely limited by the lack of reliable field data. Meanwhile, a conventional geologic approach has been taken in the current studies whereby roof failure is related to causative geologic features.

The main objective of this paper is to identify and describe some roof rock structures in the Gateway mine which have caused or promoted roof failure and roof support problems, and to outline some geologic criteria for predicting, in advance of mining, zones of potentially hazardous or unstable roof. The work was accomplished chiefly by detailed examination of at least 6 miles of entries and crosscuts and by analysis of special maps prepared from drill hole data. Although this study was conducted in only one mine, in a small portion of the Pittsburgh coalbed in southwestern Pennsylvania, some features discussed here may be characteristic of other coalbeds or other localities.

ACKNOWLEDGMENTS

The author is grateful for the full cooperation of the Jones and Laughlin Steel Corp. In particular, Gateway Coal Co. supervisors generously contributed much time in accompanying the author and his coworker underground.

GEOLOGIC SETTING

The Gateway mine is 35 miles southwest of Pittsburgh, Pa., and is midway between Uniontown, Pa., and Wheeling, W. Va. (fig. 1). The region is hilly terrain with topographic relief ranging up to 300 feet. The mine is located in the Dunkard Basin, a broad structural depression in the Allegheny Plateau in which the Pittsburgh coalbed was deposited. Large reserves of coal remain unmined at depths of 600 to 1,400 feet.

Sedimentary rocks within the basin consist of a complex arrangement of limestone, mudstone, sandstone, shale, and coal. For the most part, the rocks are laterally discontinuous, sometimes changing in facies within a few hundred feet, wedging out into lenticular forms, or grading into one another vertically. These sediments were deposited in a complex system of bays, swamps, meandering streams, and deltaic environments. The remains of the ancient stream channels often can be recognized in the rock above the Pittsburgh coalbed.

The shallow water sediments deposited in these environments were reduced in thickness and deformed internally by differential compaction, especially along the margins of sandstone-filled stream channels and around the scour

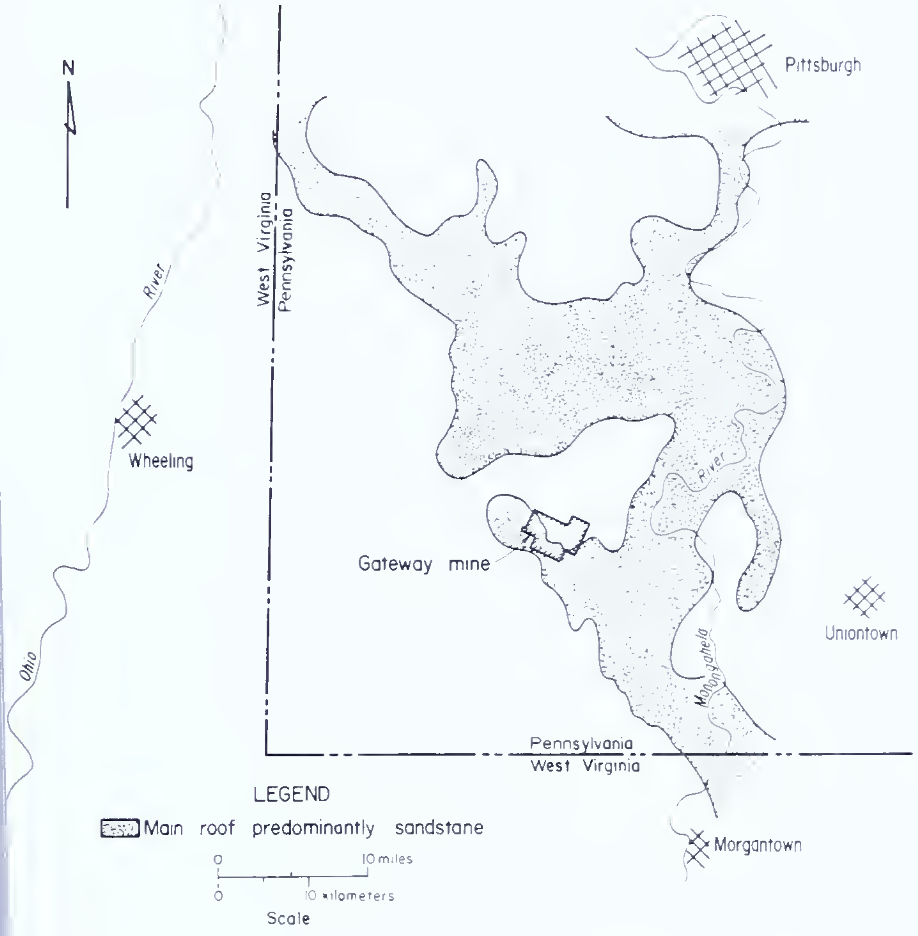

FIGURE 1. - Map showing location of Gateway mine.

marks on the underside of sandstone beds. Gentle folding of the sediments by the northwest-directed compressive forces of the Appalachian orogeny gave the Dunkard Basin its final configuration of broad open folds trending northeasterly. Structural dips of rock strata on the flanks of the folds seldom exceed 1°.

The Gateway mine is situated in a part of the basin where the rocks above the Pittsburgh coalbed are predominantly sandstone (fig. 1) and erratic in occurrence because of the complex mode of deposition. The highly irregular geometry, occurrence, and incompetence of the strata constituting the immediate and main roof of the Pittsburgh coalbed in the Gateway mine contribute significantly to mine roof support problems.

MINING METHODS

When the Gateway mine was being developed early in the century as a drift mine, the coal was extracted by the conventional retreat mining system utilizing a cutting machine, drill, and explosives to break the coal, which then was loaded and transported on track to the drift mouth on the Monongahela River. After the 1950's the milling type of continuous miner and belt haulage were adopted. Pillars are extracted by the pocket and wing method. Until recently the boring-type continuous miner was used extensively in developing mine haulageways. A section of the mine has been developed for longwall mining. Shield-type roof supports are now being used.

This report concerns only the 11 parallel main entries being advanced northwestward from the shaft (fig. 2). These entries, designated the West mains, will provide access to large reserves of coal lying to the west for many years.

A boring-type continuous miner was used to drive the West mains 6,000 feet westward from the shaft to the vicinity of 5 North (fig. 3); then a milling-type continuous miner was employed to drive the mains westward from 5 North.

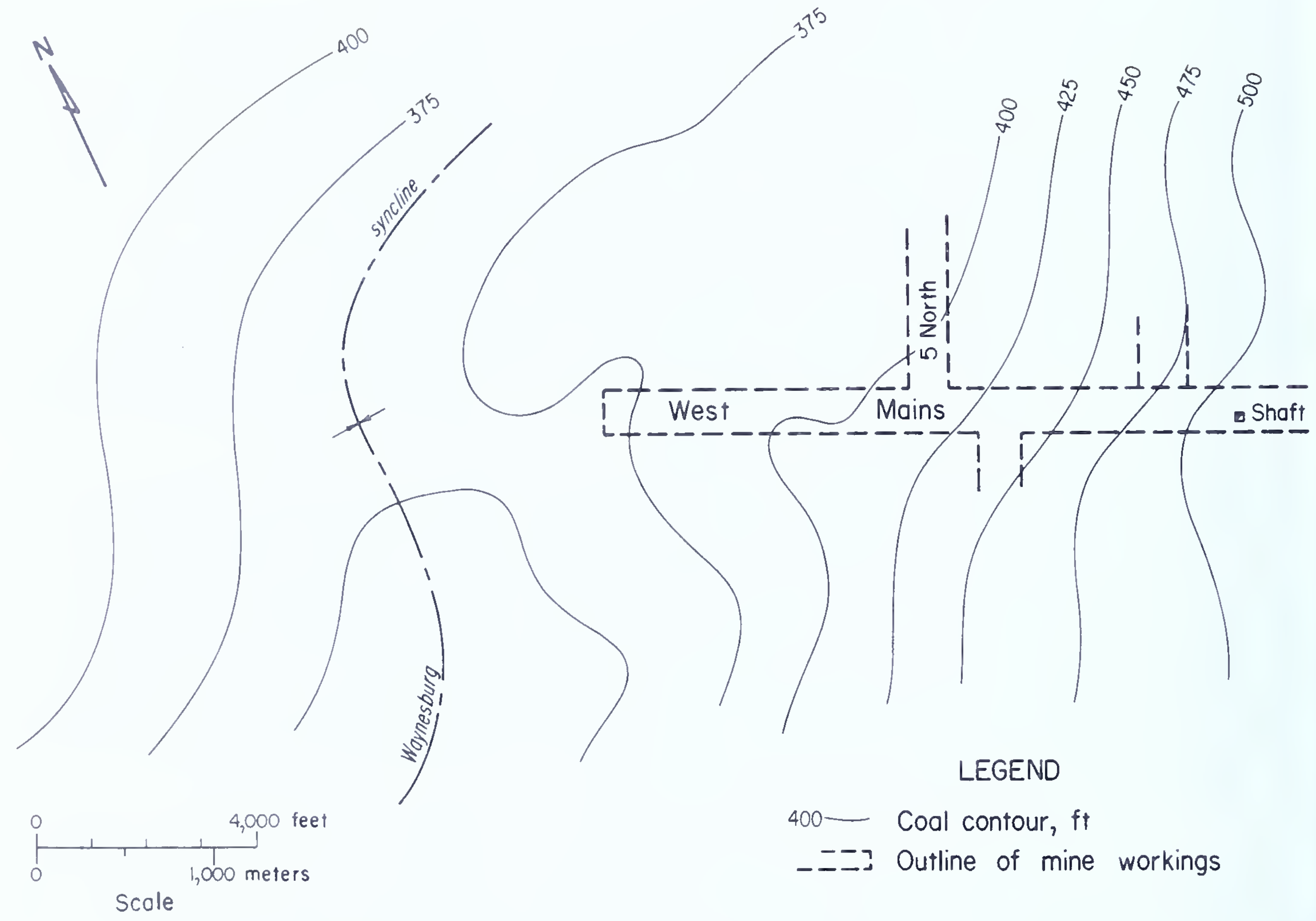

FIGURE 2. - Location of mine shaft and West mains.

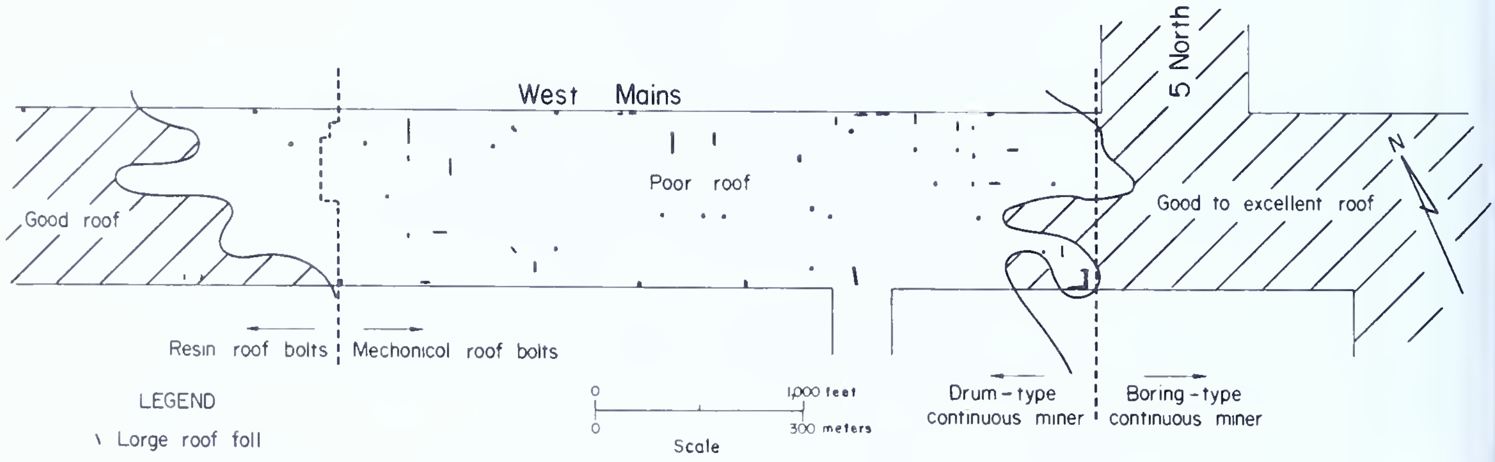

FIGURE 3. - Mining method, roof bolting, and roof falls in West mains.

The West mains entries were driven about 16 feet wide on 80-foot centers, with crosscuts on 100-foot centers at 90° angles. Full mechanical-type roof bolting was practiced throughout most of the West mains. Beginning at 3,600 feet west of 5 North, full resin bolting was adopted (fig. 3). In a large portion of the mains from 5 North westward the mine roof was highly irregular in structure and composition, generally broken, and incompetent. Roof trusses were installed in a large part of the track entry as supplementary support, and currently steel crossbars set on masonry block walls are being emplaced in the unstable zones along the track. In other entries of the West mains supplementary support consists chiefly of post, cribs, or crossbars.

ROOF SUPPORT PLAN

The original roof support plan authorized the installation of 5/8-inch-diameter tension-type mechanical bolts with a minimum length of 48 inches on a pattern of 4-foot centers. Materials used in conjunction with roof bolts included wooden planks, wedges, and roof trusses requiring angle holes located near the intersection of roof and rib. Posts with cap blocks, cribs, and posts with crossbars were used extensively as supplemental support. Also, the use of 3/4-inch-diameter, 60-inch-long resin-anchored bolts as supplemental support was approved.

The foregoing roof support plan was followed exclusively in the West mains until the entries progressed to 3,600 feet west on 5 North (fig. 3). As a result of the trial use of resin bolts for supplemental support, a roof control plan was approved on April 1, 1974, that permitted the use of resin-grouted bolts as a sole means of roof support throughout the mine. The original roof control plan was thus amended to include full resin bolting, which was used exclusively beginning 3,600 feet west of 5 North.

Roof structure in the resin-bolted section beginning 3,600 feet west of 5 North was generally more uniform and the rock was more competent than before. According to operating personnel, resin bolting has been more effective than tension-type bolts in supporting the immediate roof in the West mains.

DESCRIPTION OF ROOF ROCK

For convenience the column of strata above the Pittsburgh coalbed can be divided into three members based on predominant lithologic character: rash, sandstone, and calcareous shale (fig. 4). Beginning with the lowest member, which lies directly above the Pittsburgh coalbed, the strata consist of from 1 to 16 feet of generally incompetent interbedded mudstone, coal, and shale. The entire sequence, here referred to as rash, is highly variable in thickness and composition, with much intertonguing, pinching out, and lenticular structure. The base of the sequence is a drawslate consisting of a nonlaminated claystone which is removed during first mining because it is friable, deteriorates in moist air, and cannot be adequately supported by conventional methods. The drawslate ranges up to 3 feet in thickness. When the drawslate has been removed, a more competent bed of rider coal about 1 foot thick is bolted to form the mine roof. The rider coal also protects the overlying rash member from the effects of the moisture in the humid mine air.

The following values are representative of the basal drawslate in the rash sequence:

Compressive strength	psi..	1,883
Tensile strength	psi..	669
Modulus of elasticity	psi..	2.64×10^6
Liquid (limit)	percent..	21
Plastic (limit)	do.....	16
Plasticity (limit)	do.....	5

The sandstone member lies next in sequence above the rash and sometimes entirely replaces the rash where the rash was removed by erosion shortly after deposition. The sandstone member is variable in composition and consists of 18 to 50 feet of shale, sandy shale, or sandstone. The sandstone occurs as thin sheetlike beds, lenticular bodies, thick massive beds, or narrow stream channel fillings (fig. 5). While the thin beds (1-2 feet) are sheetlike in form, the lower surfaces of the thicker, more massive beds commonly are irregular in form with irregular convex, wavelike scour marks; sometimes these are linear trends, where depressions in the underlying rock formed by stream currents were filled. The linear scour marks strongly resemble the usually longer sandstone filling of a stream channel--the "horseback" of miners' terminology and sometimes it is impossible to distinguish between a channel and a scour mark where the two are not fully exposed. The undersurfaces of both irregular scour marks and linear stream channels are almost always heavily slickensided owing to the effects of differential compaction.

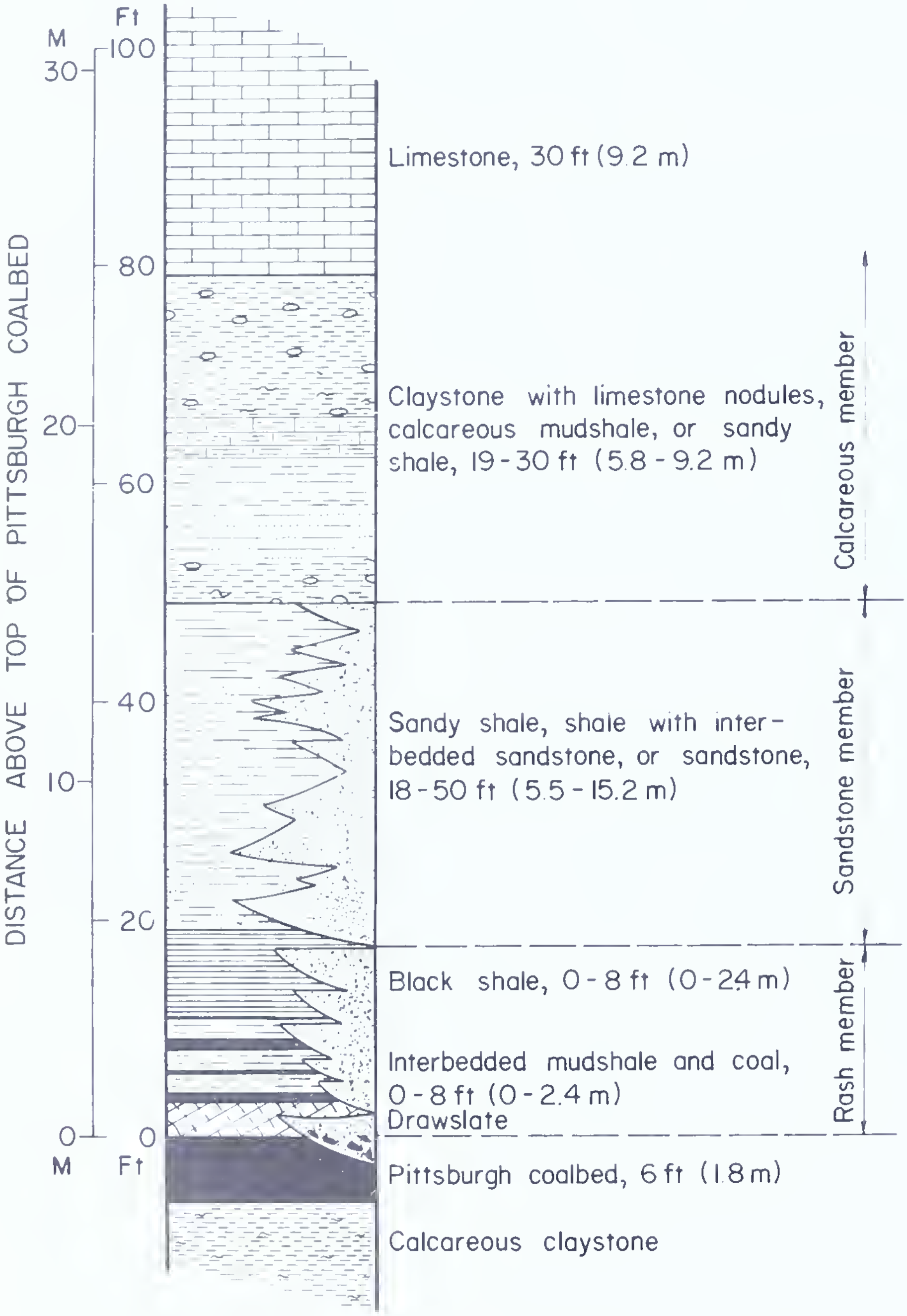
M
Ft
30
100
80
20
60
40
10
20
0
0
M
Ft
DISTANCE ABOVE TOP OF PITTSBURGH COALBED
Limestone, 30 ft (9.2 m)
Claystone with limestone nodules, calcareous mudshale, or sandy shale, 19-30 ft (5.8-9.2 m)
Calcareous member
Sandy shale, shale with interbedded sandstone, or sandstone, 18-50 ft (5.5-15.2 m)
Sandstone member
Black shale, 0-8 ft (0-2.4 m)
Interbedded mudshale and coal, 0-8 ft (0-2.4 m)
Drawslate
Rash member
Pittsburgh coalbed, 6 ft (1.8 m)
Calcareous claystone

FIGURE 4. - Generalized columnar section of mine roof rock.

The sandstone is micaceous, argillaceous, and medium grained. Some beds are poorly cemented, and friable, and disintegrate rapidly into loose sand, while other beds separate readily along mica-rich bedding planes into flaggy slabs known to miners as stackrock. Gravel consisting of rounded fragments of shale and coal occurs at the base of some sandstone bodies, particularly the channel fillings. Thin, flat or curving fragments of coal material also occur in some sandstone beds, seriously reducing the strength of the rock, which is then called "trashrock" or "trashy" by miners. Crossbedding is common in nearly all forms of sandstone.

The following values are representative of the physical properties of massive sandstone from the West mains roof rock:

Compressive strength	psi	8,124
Tensile strength	psi	554
Modulus of elasticity	psi	0.58×10^6
Water saturation	percent	3.2

These values are well within the range of test results obtained from Pittsburgh sandstone in adjacent areas of southwestern Pennsylvania. However, these values do not reflect the planes of weakness frequently encountered in sandstone drill core, such as micaceous layers, crossbedding, or coal inclusions. Samples that include these features are seldom selected for testing, so that the geologist's log must be searched for clues as to minimum strength or incompetency.

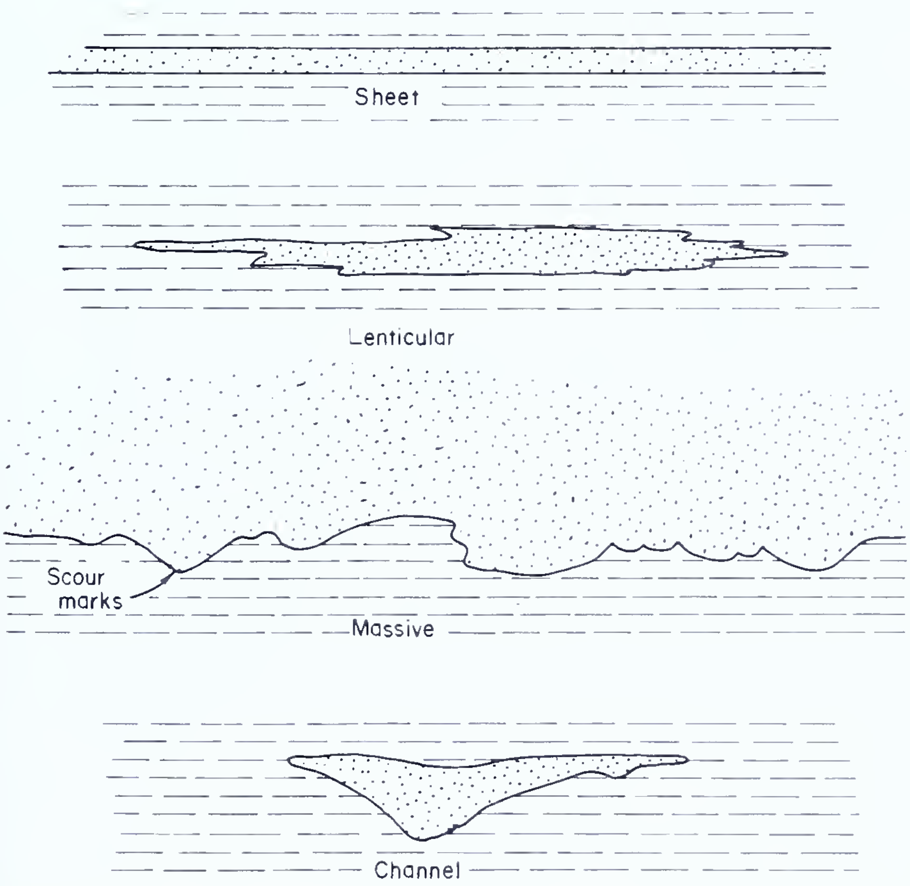

FIGURE 5. - Common forms of sandstone bodies occurring in mine roof rock.

In some areas of the West mains, the rash member had been completely eroded by stream action and sandstone had been deposited in its place directly on the coalbed. Elsewhere, stream erosion continued to cut into the upper few feet of coal, resulting in narrow sandstone-filled stream channels which constitute the miner's "horseback" or "roll." In the West mains of the Gateway mine, rolls are typically about 15 feet wide and 30 to 100 feet long, although some are up to 60 feet wide and 400 feet long. The discontinuous character of the rolls suggests that they were formed by a braided stream system; that is, one in which several shallow channels become filled with sediment so new branches were formed, resulting in an interlacing and discontinuous pattern of channels.

The sedimentary structures in the rash and sandstone members often could not be identified with certainty as either channels, scour marks, or slumps. Most structures were only partially exposed by roof falls, and the effects of compaction tended to obscure the original character of features. As a result of differential compaction the lower surface of virtually every basal disconformity is heavily slickensided, and the underlying shale, mudstone, or coal is distorted. The slickensides tended to wrap around the sides of the narrow deep channels, particularly where the sides of the channel were somewhat undercut or where convex scour marks occurred. Slickensides that parallel the linear channels always occur within a very few feet of the channel boundary; however, numerous slickensides occur randomly throughout all the argillaceous rocks in the rash member. It is suspected that some of the pronounced linear trends of slickensides observed in the rash roof rock may follow sandstone-filled channels located a short distance above the roof, but this can be confirmed only by drilling test holes.

RELATION OF ROOF PROBLEMS TO GEOLOGY

Development of the 11-entry West mains westward from the shaft progressed without unusual or severe roof problems until the vicinity of 5 North was reached. This interval of approximately 6,000 feet was mined partly with a boring-type continuous miner and partly with a milling-type machine. The roof was supported by mechanical roof bolts 6 to 10 feet long and by occasional posts and crossbars. The boring machine carved an arched cut at the intersection of rib and roof, which is an advantage in roof support. The roof in this interval consisted almost entirely of uniformly bedded rocks of the rash member overlain by shale and sandy shale of the sandstone member, but there were no sandstone beds or channels (fig. 6). In this section of the mains the coal dipped westward at a slope of about 1.7 percent.

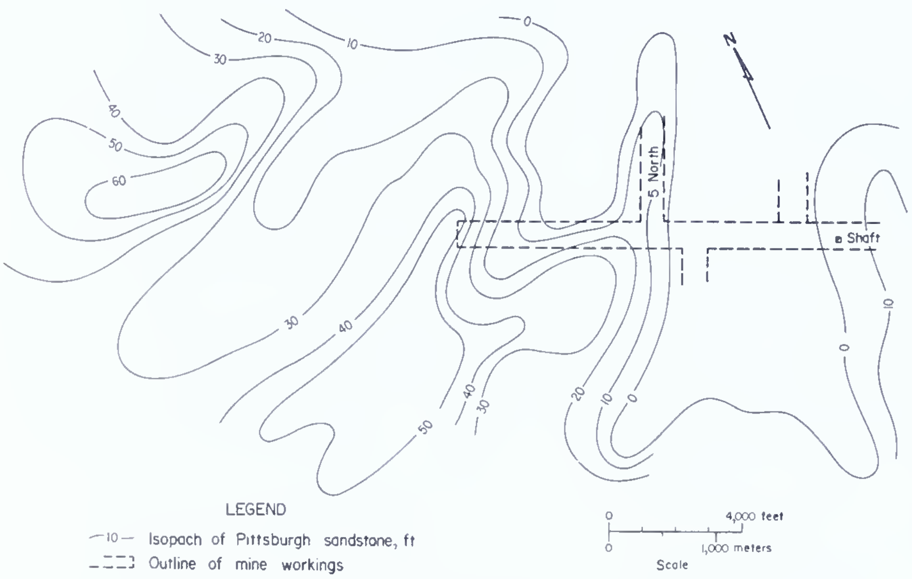
0
10
20
30
40
50
60
N
5 North
Shaft
LEGEND
—10— Isopach of Pittsburgh sandstone, ft
- - - Outline of mine workings
0
4,000 feet
0
1,000 meters
Scale

FIGURE 6. - Isopach of Pittsburgh sandstone.

In the vicinity of 5 North, roof conditions deteriorated. A milling-type continuous miner was used exclusively from 5 North westward (fig. 3), and sandstone was encountered in the roof (fig. 6). The base of the sandstone ranged from 10 to 25 feet above the coal (fig. 7), except where small narrow channels had cut down to the top of the coalbed.

Serious problems of irregular, rolly, broken, incompetent roof plagued the West mains for the next 5,000 feet. Then the irregularities diminished and the roof became more uniform. The base of the sandstone member now occurred within 10 feet of the coal, and full resin bolting of roof with 5-foot bolts was adopted, with generally improved roof conditions. Thus, several factors may have contributed to the changing roof stability.

All evidence indicated that the geology of the immediate roof probably was the chief factor governing roof conditions encountered in advancing the West mains. At this stage it was decided to proceed with a detailed examination of the roof, entailing some 6 miles of entries, in the hope of gaining some insight into the cause of the hazardous zone of roof. This work included the following mapping:

1. Trends of major roof rolls and slickensided zones.
2. Selected structures exposed in large roof falls.

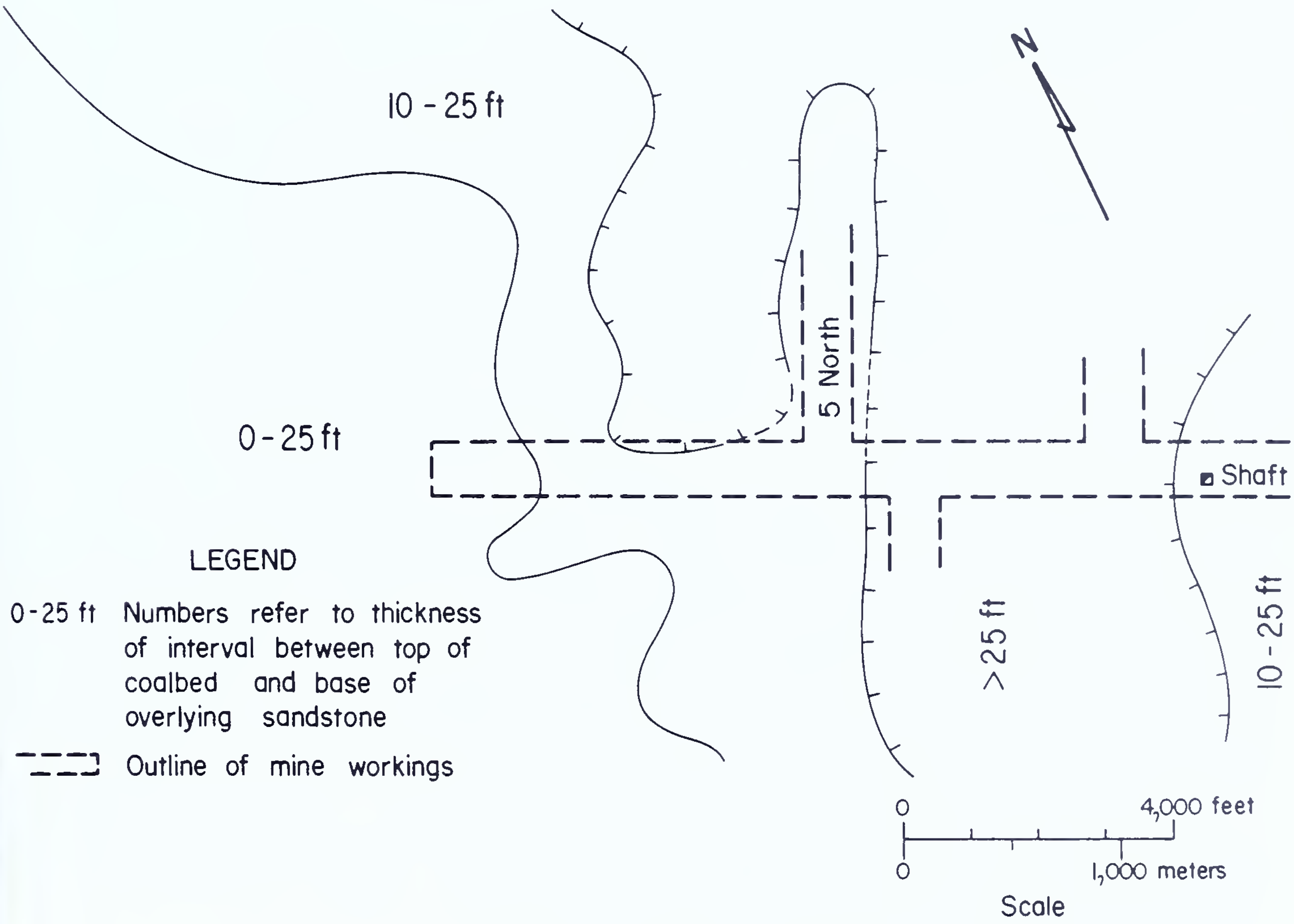

FIGURE 7. - Isopach of rash member in immediate roof rock.

3. All large roof falls.

4. Roof condition.

During this mapping it became obvious that the pattern of large roof falls was scattered (fig. 3) owing to the localizing effect of entries and intersections. It also was obvious that virtually every instance of irregular, broken, unstable, troublesome roof could be attributed to geologic structures that interrupted the uniformity or continuity of the roof strata, or weakened the bond between the strata. In order of importance, these are the troublesome roof structures identified:

1. Sandstone-filled channels and scour marks.

2. Large slickensides.

3. Abrupt lateral pinchout or wedging of strata.

4. Weak bonding between thinly laminated sandstone strata, such as flaggy sandstone or "stackrock."

5. Poorly cemented friable sandstone.

The five problem areas are described in the following pages.

Channels

The underlying cause for the high incidence of roof failure near channels is the abundance of slickensides on the undersurfaces. The slickensides constitute planes of weakness and a lack of bonding so that the weak rash type of rock directly beneath and adjacent to the channel separates readily from the sandstone-filled channel as soon as the coal is removed. There is a similar tendency for rash to separate from the undulating and slickensided surfaces of scour marks on the underside of thick sandstone beds. In the West mains these conditions were particularly severe because the overall trend of the channels, N 50 W, was close to the N 65 W direction in which the mains were driven. This relation is illustrated in figure 8, which also shows the generally similar orientation of the elongate channel troughs in the mine roof over a large area. Penetration of these channels at a more obtuse angle might have facilitated progress and reduced roof support problems.

The widely ranging character of channels is illustrated by drawings and photographs of these structures made in the West mains where roof falls had exposed some of the details. Figure 9 comprises photographs of the typically narrow linear sandstone-filled channels, with slickensided undersurfaces, cutting into weak mudstone and coal which has fallen away from the margins of the roll. Commonly, one side of the channel is steep and the other gently sloping. While the trough filling of the channels is generally competent, the marginal mudstone is weak, softens when exposed to moist mine air, and is supported only with difficulty. The mudstone usually requires straps or blocks in addition to bolting for support.

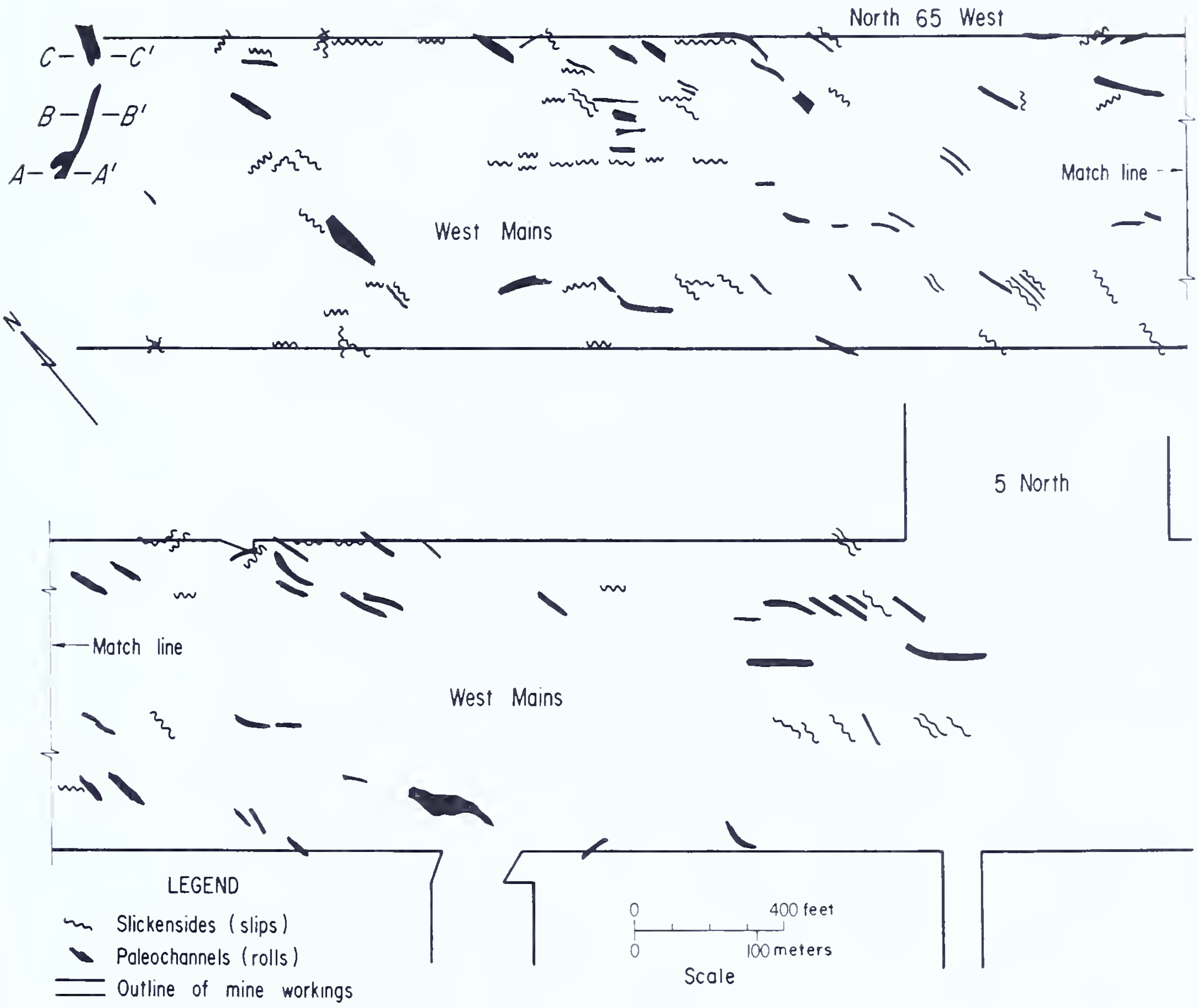

FIGURE 8. - Map showing trends of major slickensides and paleochannels in West mains between 5 North and face.

Figure 10 illustrates a common form of sandstone-filled channel or scour encountered in the West mains, complicated by a lenticular body of sandstone on the right edge of the entry. In this example, it was impractical to support the discontinuous beds and distorted mudstone below the massive sandstone, so that 4 feet of rock above the coalbed either fell or was removed before the roof could be secured. Another alternative, that of also setting posts and crossbars, would have been slower and more costly, and unnecessary with a stable competent roof of massive sandstone.

Figure 11 shows three cross sections of a complex channel structure penetrated near the face of the West mains. The trend of this particular channel was unlike that of most others in the section, and it was an isolated feature. The sandstone was very hard for the miner to penetrate, and yet in some places it tended to separate into sharp wedges and slabs that required the use of supplementary bolts and steel straps to provide adequate support.

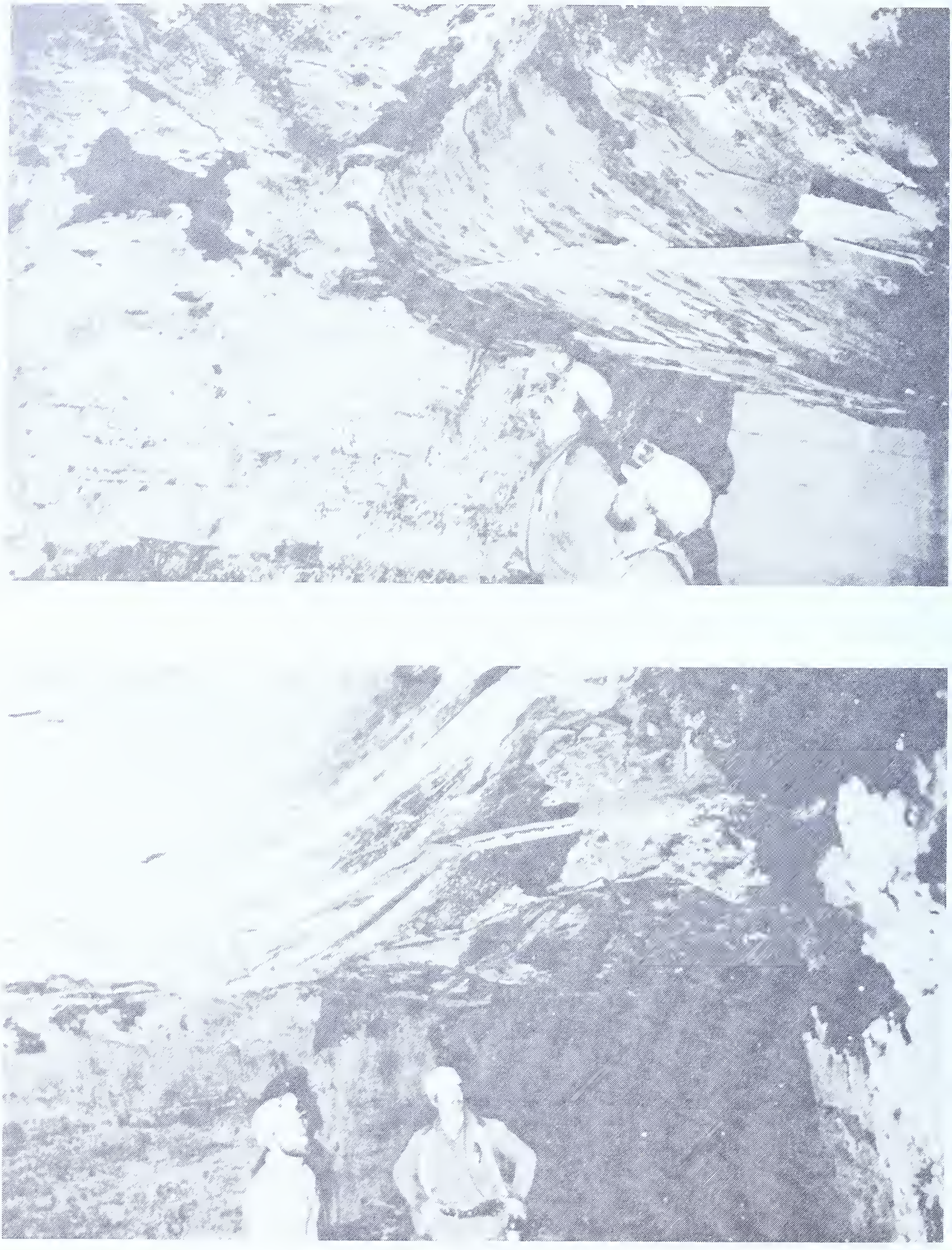

FIGURE 9. - Slickensided sandstone-filled channel in roof of West mains.

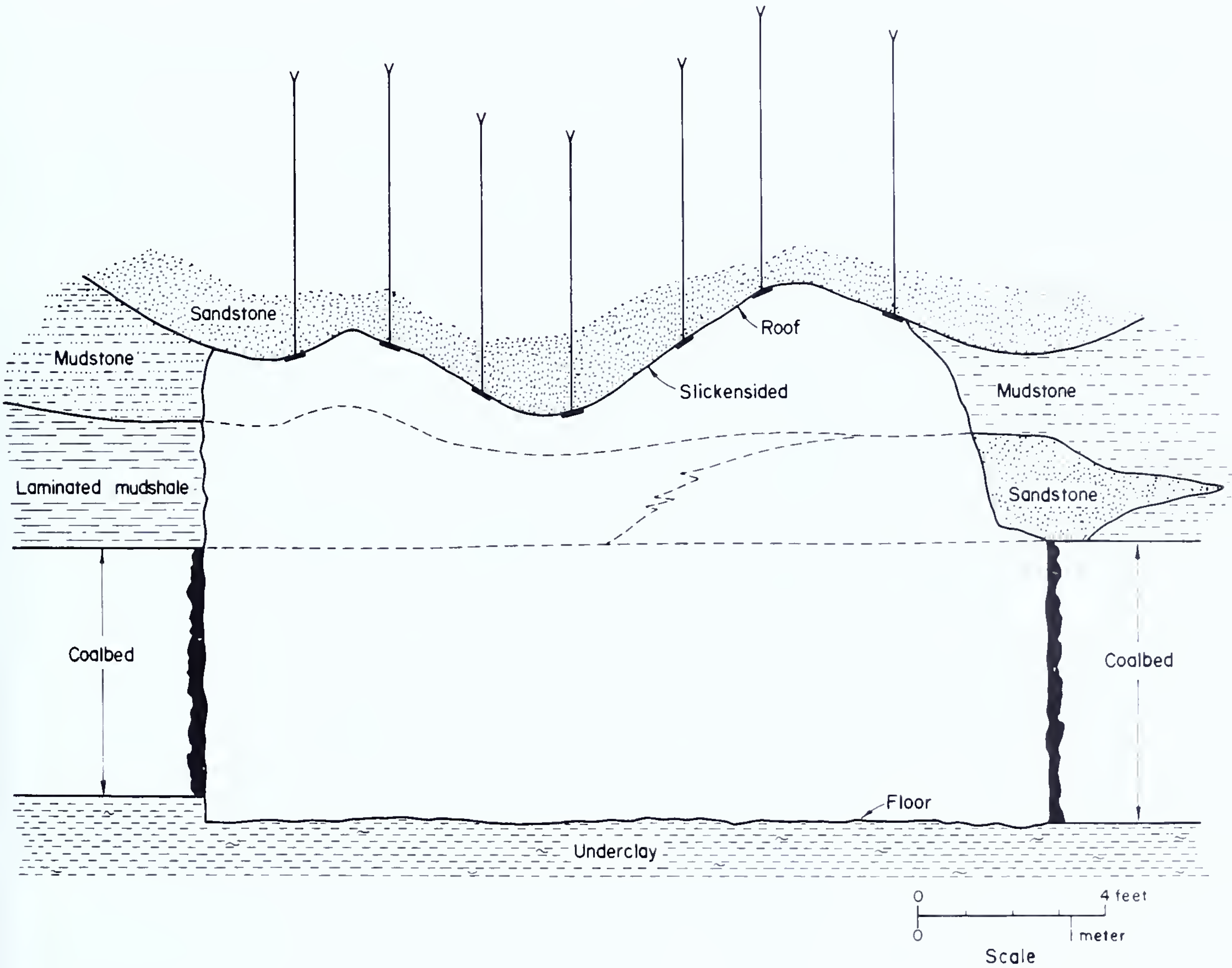

FIGURE 10. - Cross section of sandstone-filled channel or scour marks in roof of West mains.

The roof bolt holes and three shallow core-drilled holes show that the roof consists entirely of sandstone for at least 5 feet above the top of the coal.

Figure 12 illustrates another example of a complex sandstone-filled channellike structure occurring in the West mains. A sizable roof fall on each flank of the structure indicates the incompetent nature of the coarse sandstone, while the rash member above the coalbed has been partly removed during mining and the remainder has failed by attrition and separated along the contact with the overlying shale.

In contrast to the small channels that occur in the main entries west of 5 North, a large mudshale-filled channel or washout in the coalbed several hundred feet wide was penetrated by the main entries about 1,000 feet east of the shaft (fig. 13). This entire zone was examined to determine the effects of the washout on roof stability. No severe roof problems were encountered either beneath, or marginal to, the washout. This observation,

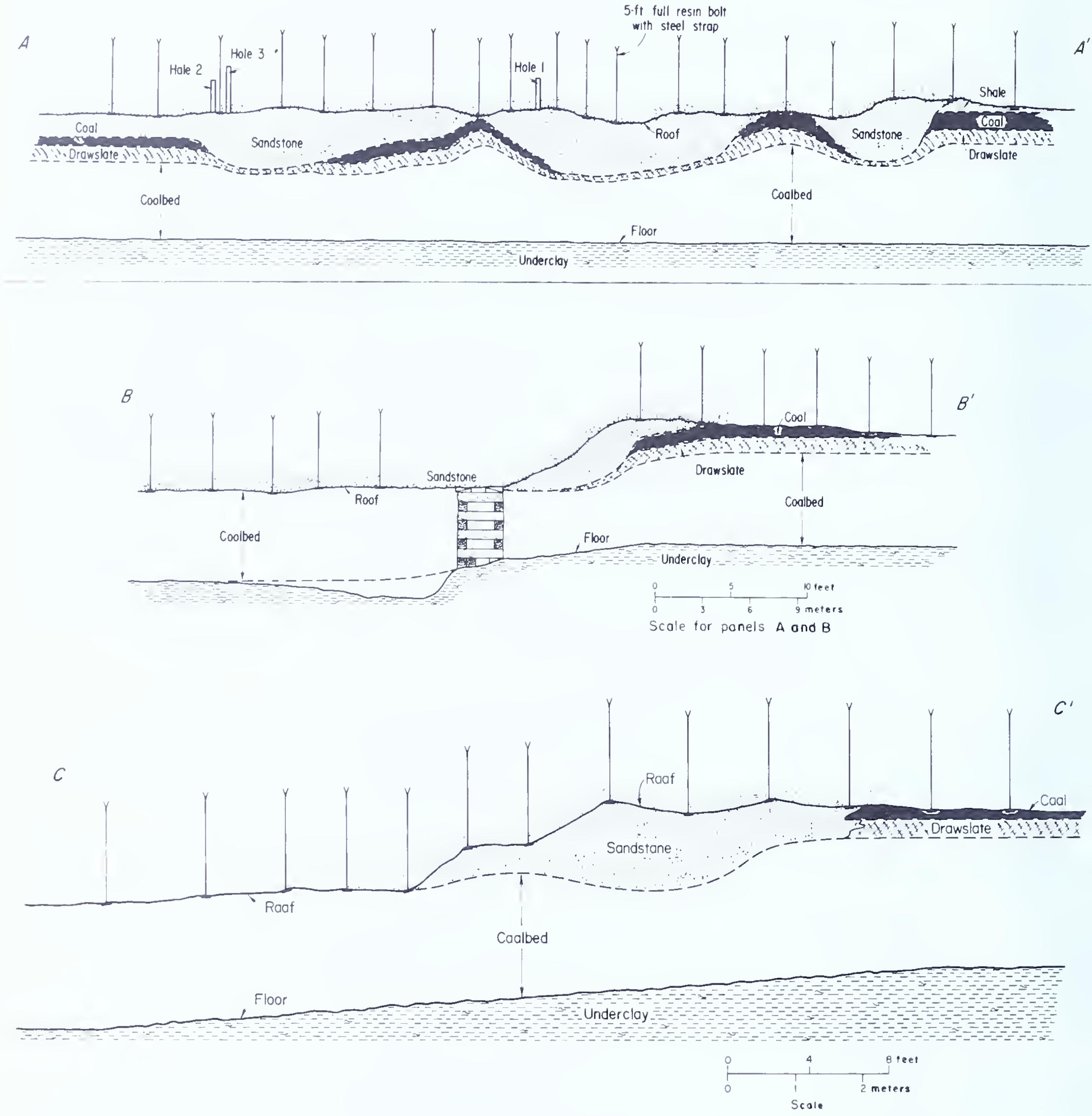

FIGURE 11. - Cross sections of sandstone-filled channel complex in West mains. For location see figure 8.

along with a description of roof conditions in other washout areas in the mine, indicates that while small channels are very troublesome to mine under and support, the broad washouts seldom are associated with severe roof problems. However, some roof support problems have been reported along the flanks of large washouts in the Pittsburgh coalbed of southwestern Pennsylvania. The character of these washouts and techniques for their detection

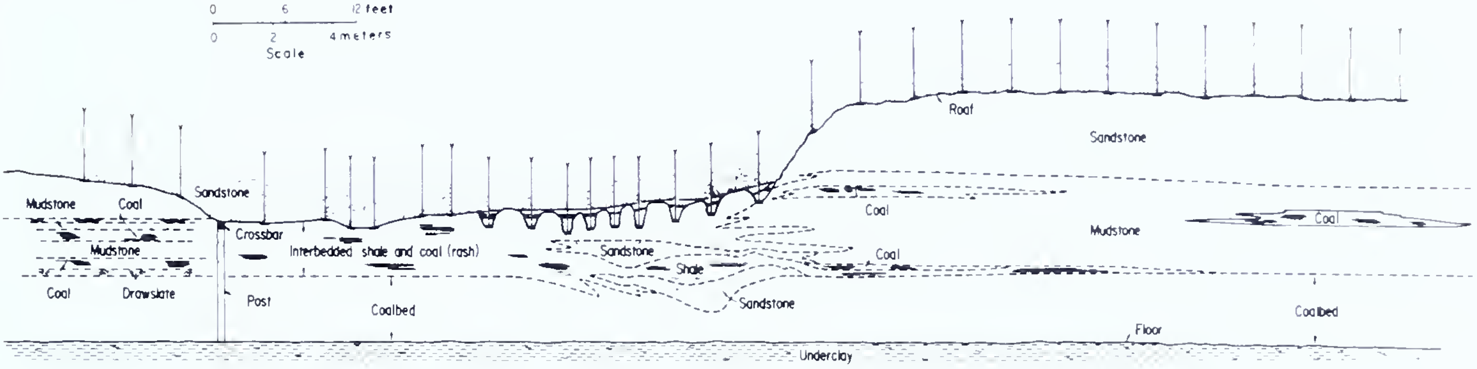

FIGURE 12. - Cross section of a complex channel structure in West mains.

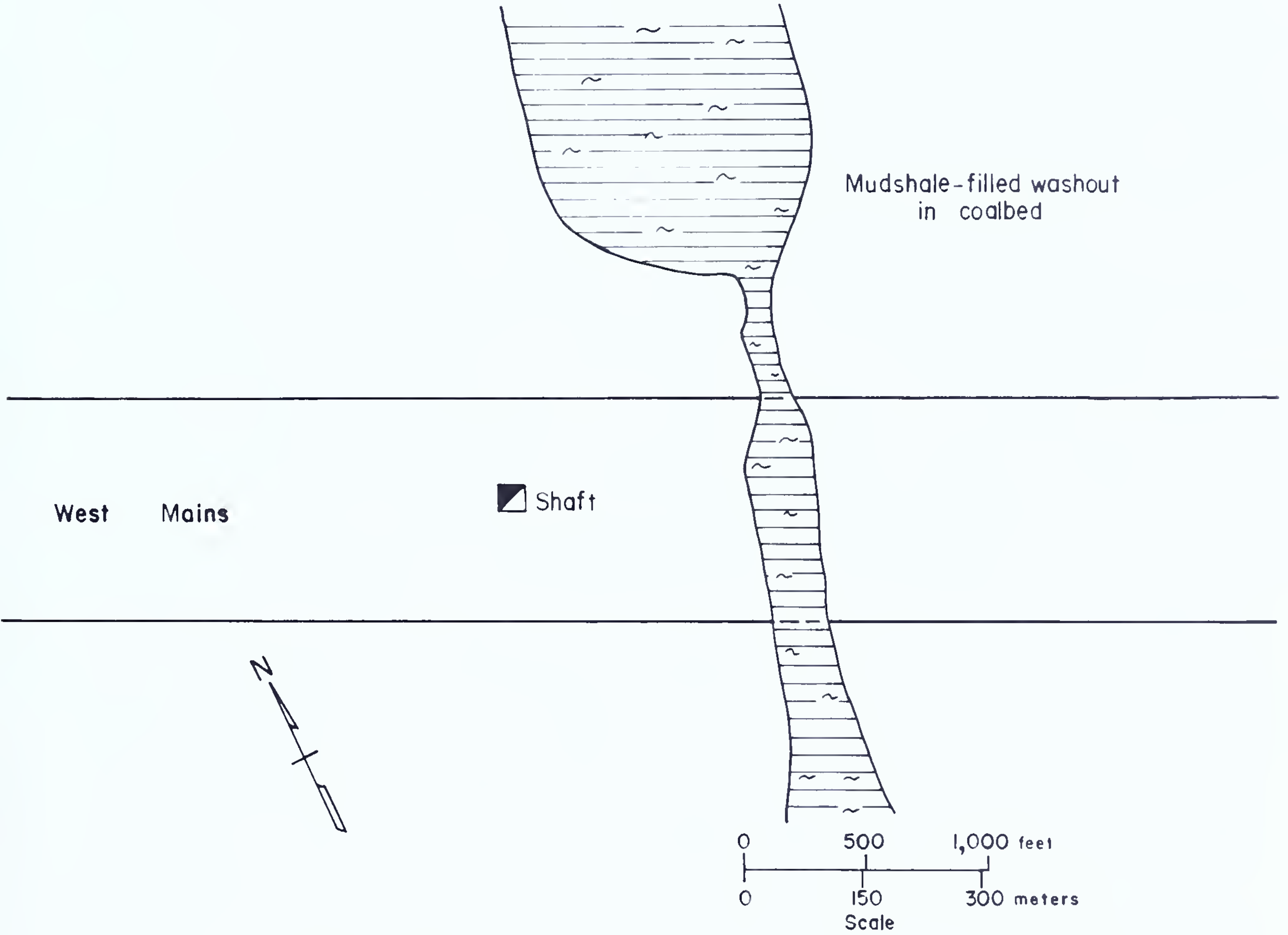

FIGURE 13. - Siltstone-filled washout penetrated east of shaft by West mains.

have been described by McCulloch, Diamond, Bench, and Duel,[4] who indicate that at least in some instances they may be used to delineate zones of potential roof instability.

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[4] McCulloch, C. M., W. P. Diamond, B. M. Bench, and M. Deul. Selected Geologic Factors Affecting Mining of the Pittsburgh Coalbed. BuMines RI 8093, 1975, 72 pp.

It is impossible to describe exactly the complex sandstone deposits and channel or scour structures that were exposed in the roof of the West mains. Only a few of the fairly typical underground exposures have been illustrated, but these are adequate to show the general character of the roof rolls and confirm their origin as sandstone- and siltstone-filled troughs scoured out by the action of localized stream currents. Crossbedding is common in these structures, further evidence for deposition by a meandering stream either within the distributary channel or along the banks.

The structures observed in the West mains occur near the base of a thick distributary channel sandstone deposit (fig. 14) which intertongues laterally with delta fringe shale. Channel and scour structures probably occur throughout the main sandstone body but are not easily distinguished because of similar color, texture, and composition. However, at the base of the sandstone the scours into the immediate roof coal form a striking contrast with flanking softer sediments. In addition, the basal portions of the main sandstone body commonly incorporate ragged fragments of carbonized vegetation known as "rafts" or "trash," derived during the peat stage by scouring of the main coalbed and rider coal.

The hazards of mine roof, in which channel structures are bordered by large slickensides as just described, are illustrated by referring to a fatal

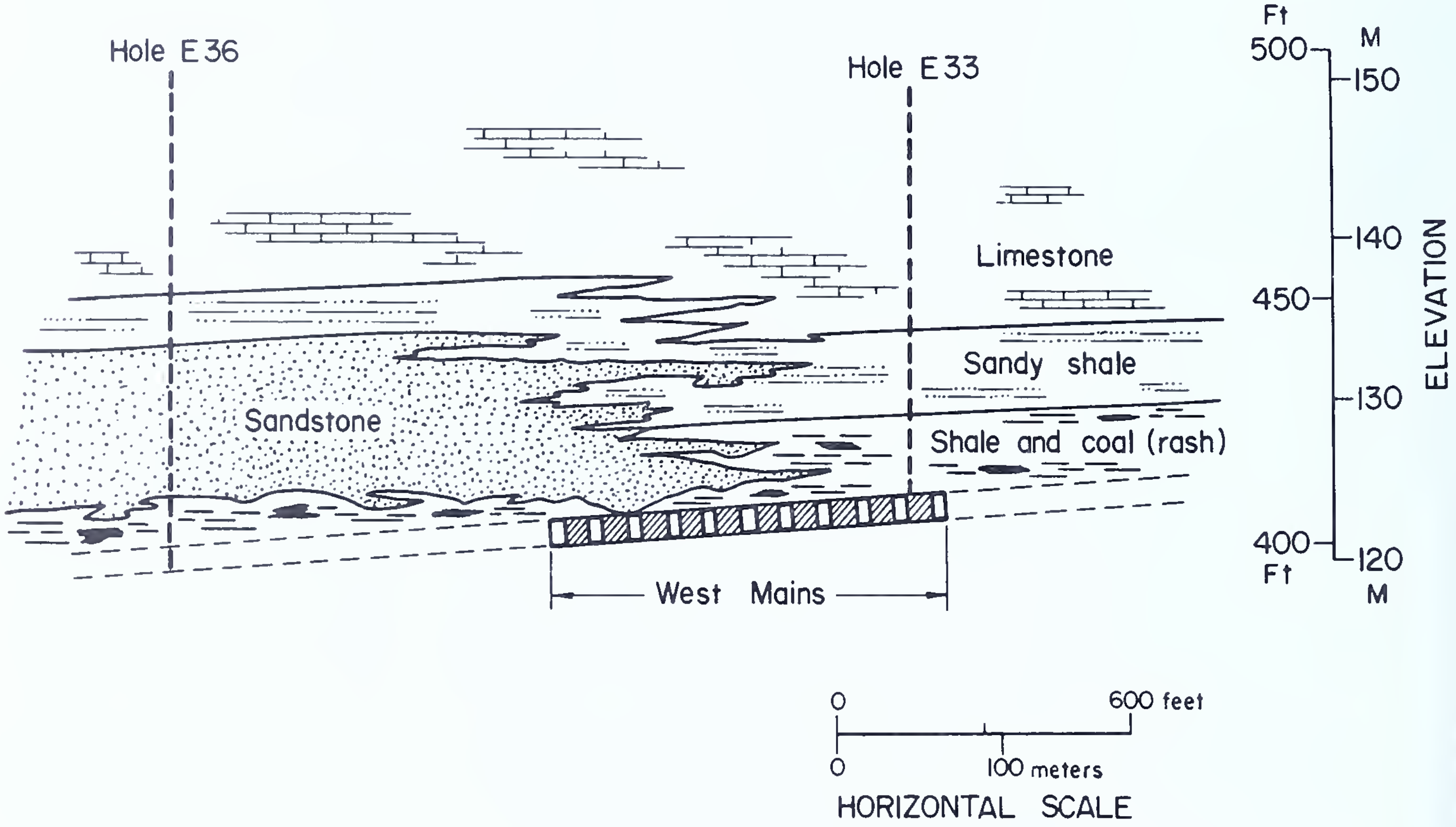

FIGURE 14. - Cross section of sandstone body showing relation of undulating basal contact to West mains.

roof fall accident that occurred in Center County, Pa., in 1969[5] during scaling of a previous fall on the main belt. A large shale slab 10 inches thick broke away from the flank of sandstone-filled channel (fig. 15) and fell without warning directly on top of the first fall, killing one miner and injuring another. Figure 15 was transcribed directly from the accident report and shows the pertinent structure clearly.

Slickensides

Large slickensides invariably are highly developed around the troughs of scours and channels; they also occur between channels, where their origin is more obscure. However, most slickensides are probably related to compaction diagenesis. Considerable skill is required by roof bolters to recognize the full expanse of a large slickenside and the potential hazard of a cantilevered or isolated wedge of roof rock and to bolt the structure in the most effective manner. The planes of interchannel slickensides range widely in dip, but commonly dip is about 20° to 30°, which responds well to conventional vertical bolting. Steeper slickensides probably could be more effectively supported by roof bolts angled nearly normal to the slip plane.

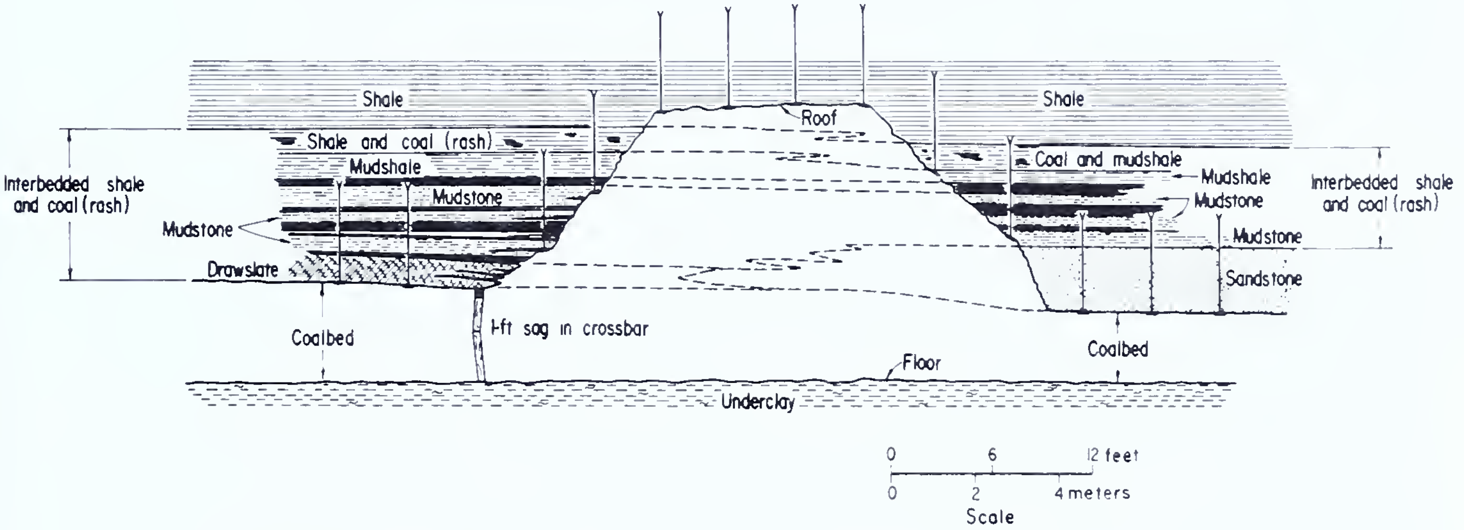

FIGURE 15. - Cross section of roof fall showing channel structure.

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[5] Cagely, W. C., and W. O. Montgomery. Report of Fatal Coal-Mine Roof-Fall Accident, Rushton Mine, Center County, Pa. Aug. 13, 1969, 7 pp.; available for consultation at the Mining Enforcement and Safety Administration, Federal Bldg., Johnstown, Pa.

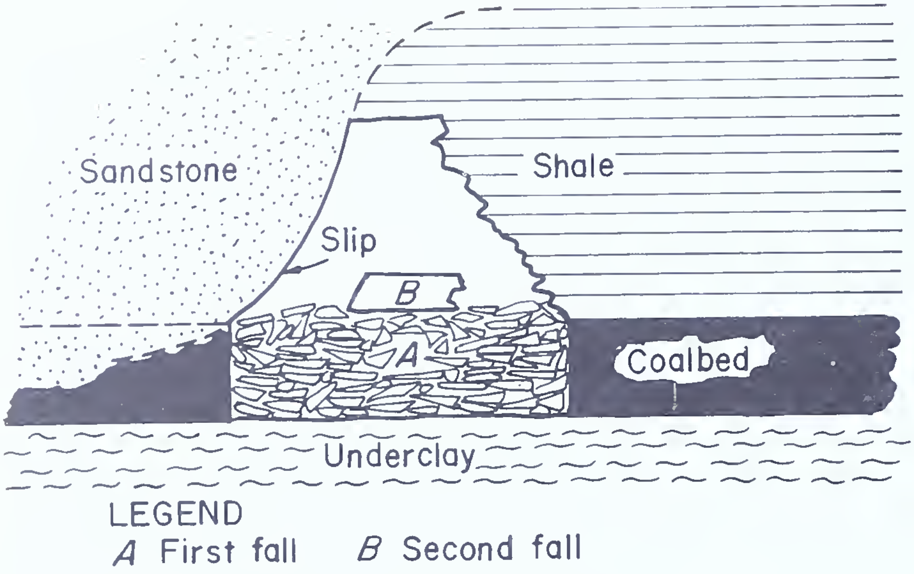

FIGURE 16. - Cross section of roof fall showing sandstone pinchout or lateral discontinuity.

Pinchout

The pinchout or lateral discontinuity of strata is illustrated in figure 16, where the 4-foot-thick sand stone in the immediate roof on the right side of the fall is absent on the left side, less than 30 feet away. There is little doubt that the discontinuous nature of the sandstone resulted in a less competent roof than would be offered by a continuous bed. An indication of this condition is that the roof at the left side of the fall has sagged more than 1 foot, while on the right side the roof supported by the 4-foot-thick sandstone bed shows no visible deflection.

Weak Bonding

Thick, massive, well-cemented sandstone in some areas of the West mains forms a highly competent roof in the Gateway mine, but much of the sandstone is thin bedded and flaggy, and this is difficult to support. Figure 17 shows flaggy sandstone exposed in the edge of a large roof fall. It is sometimes referred to by miners as stackrock. Further weakening of sandstone roof may be caused by the inclusion of coal fragments (fig. 18).

Weak Cementation

The natural material that cements the grains of the sandstone roof rock varies widely in composition but consists predominately of clay, silica, and some calcium carbonate. Sandstones with a high percentage of clay cement, which are common in several locations in the West mains, tend to be friable, and on exposure to humid mine air disintegrate gradually into loose grains of sand. This might explain the tension loss in some mechanical bolts where the bore of the hole around the anchor consists of clay-cemented sand grains that become loosened on exposure to air.

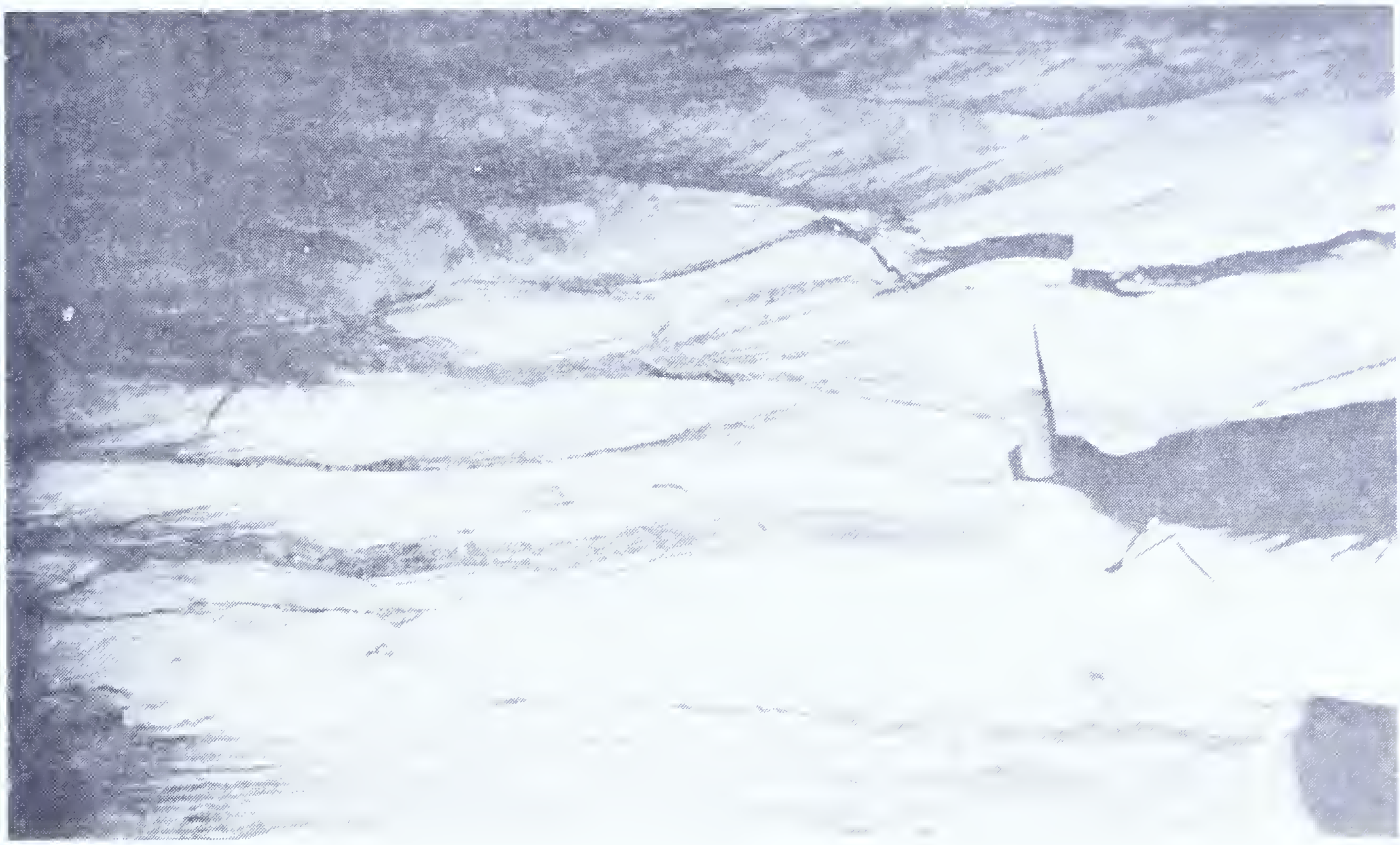

FIGURE 17. - Incompetent flaggy sandstone exposed in West mains roof fall.

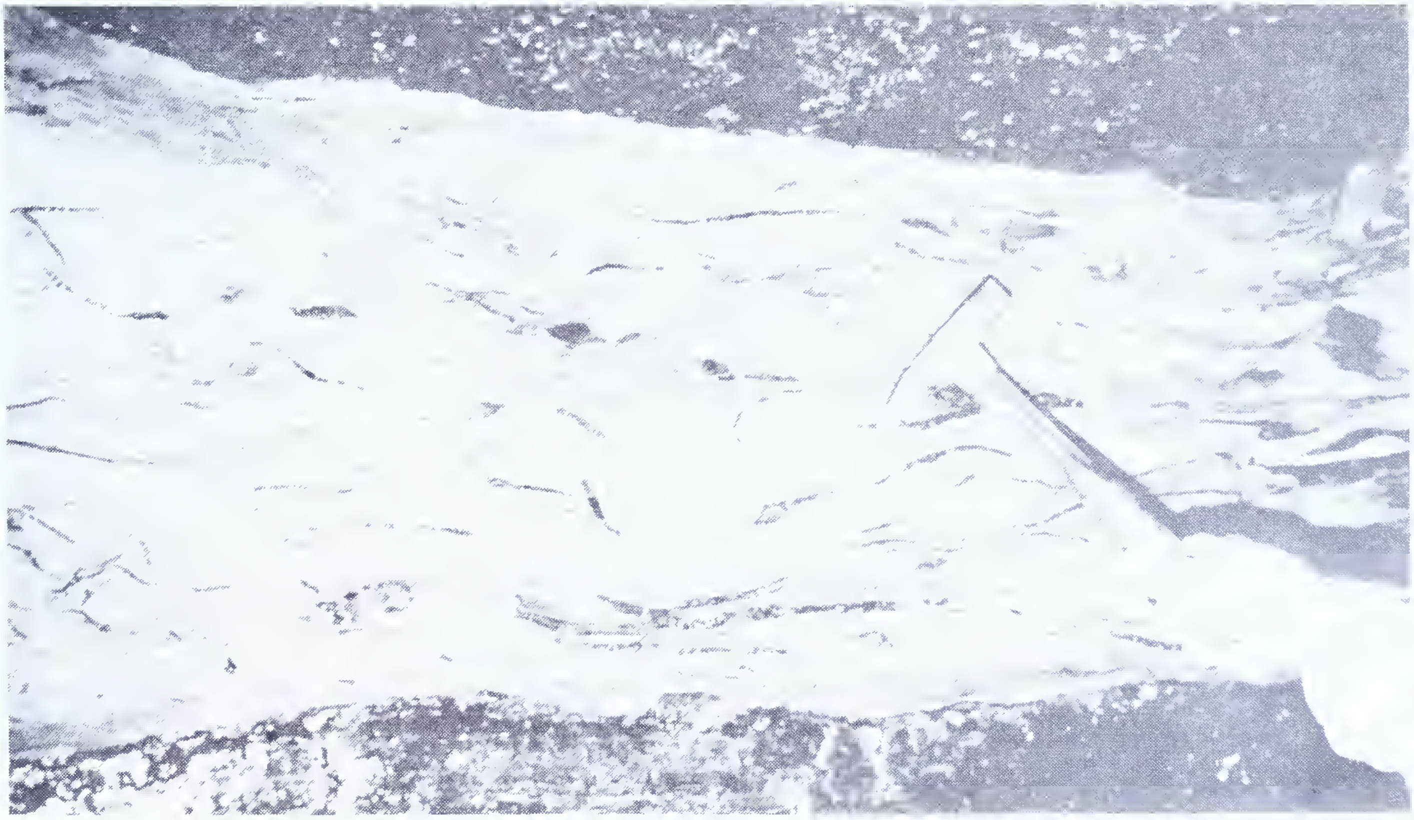

FIGURE 18. - Incompetent "trashy" sandstone containing carbonized vegetation exposed in West mains roof fall.

PREDICTIVE TECHNIQUES

After the roof in the entries of the West mains had been examined, drill core data from exploratory drilling in the area were compiled and analyzed to determine if the poor roof conditions and trends of troublesome structures in the mains could have been predicted in advance of mining. Some difficulty arose through using the drillers' logs because the description of the core was either incomplete or inaccurate. No core samples of roof rock had been preserved, and therefore no information on the lithology or mechanical properties of the sandstones could be obtained for geologic evaluation. Drill hole spacing ranged from 400 to 4,000 feet, and with the available information some maps were constructed to show geological conditions that were indicative of potentially bad roof.

The coal contours (fig. 2) show a rather uniform westward slope of 1.25 percent between the shaft and face, except for slight flattening west of 5 North. Several local swags and steepened dips were observed along the length of the West mains, but these could not be detected by the widely spaced drill holes and had no visible bearing on roof conditions.

An isopach map of the Pittsburgh sandstone roof rock (fig. 19) shows two features that might indicate contrasting roof conditions in the mains between

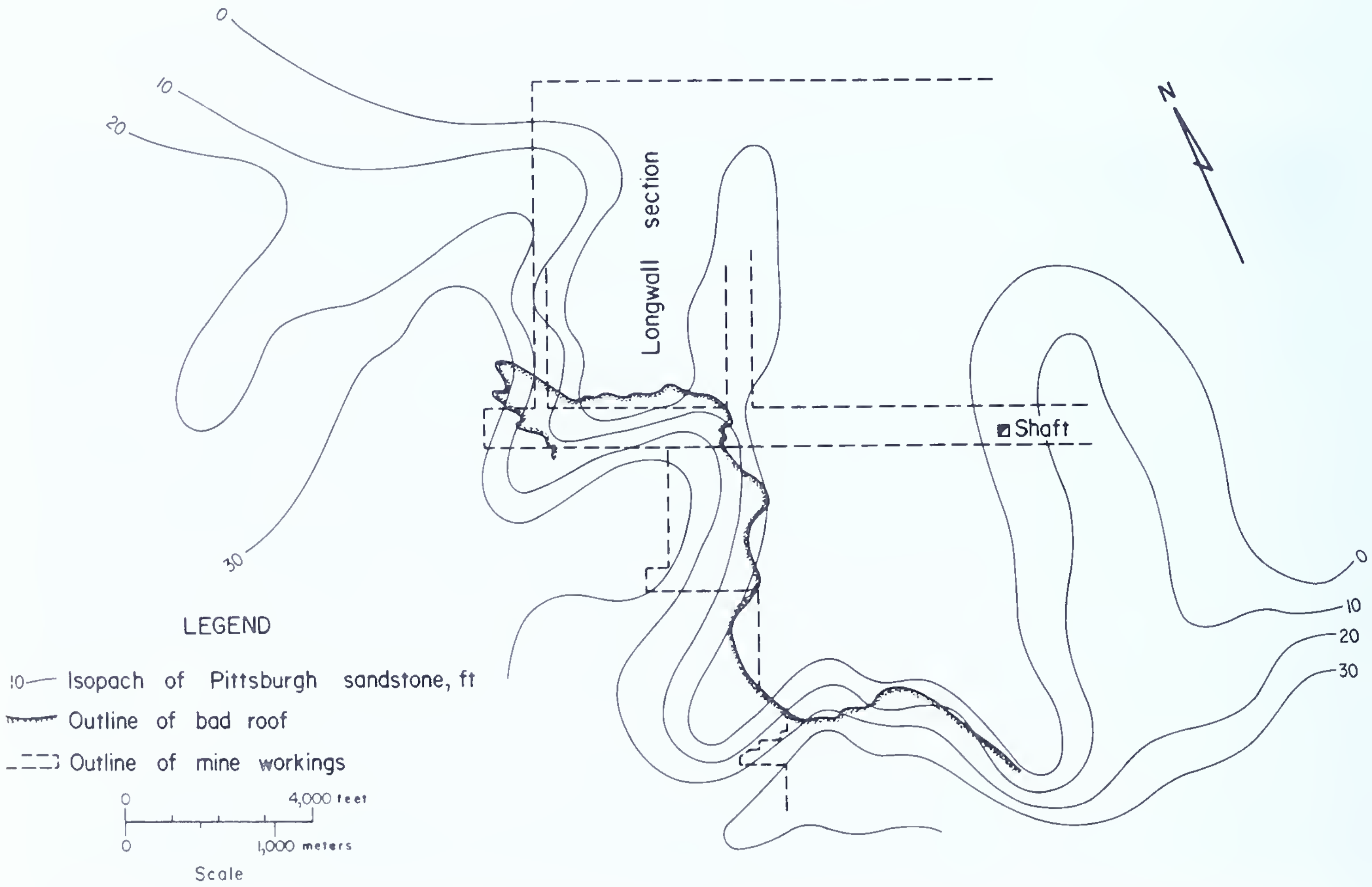

FIGURE 19. - Isopach of Pittsburgh sandstone in relation to area of bad roof conditions in West mains.

the shaft and face. In the 4,500-foot-long zone between the zero isopachs sandstone is absent, and this zone should have been free of irregularities and slickensides associated with sandstone-filled channels. This zone did indeed correspond with the best roof in the West mains. West of this zone the drill logs indicated a thickening sandstone, and this coincided with the occurrence of numerous sandstone-filled channels, scours, slickensides, and generally poor roof. Thus figure 19 illustrates a general correlation between the zone of bad roof encountered in and adjacent to the West mains, and portions of the sandstone isopach where the lines are closely spaced. This relation suggests the probability that bad roof conditions will be encountered near the boundary of the sandstone where abrupt thickening occurs.

An isopach map of the rash member lying between the coalbed and the base of the sandstone member (fig. 20) shows that good roof is found in the West mains where sandstone is either less than 10 feet or more than 25 feet above the coalbed, and poor roof occurs where the base of the sandstone is 10 to 25 feet above the coalbed. Here again, a predictive technique is suggested.

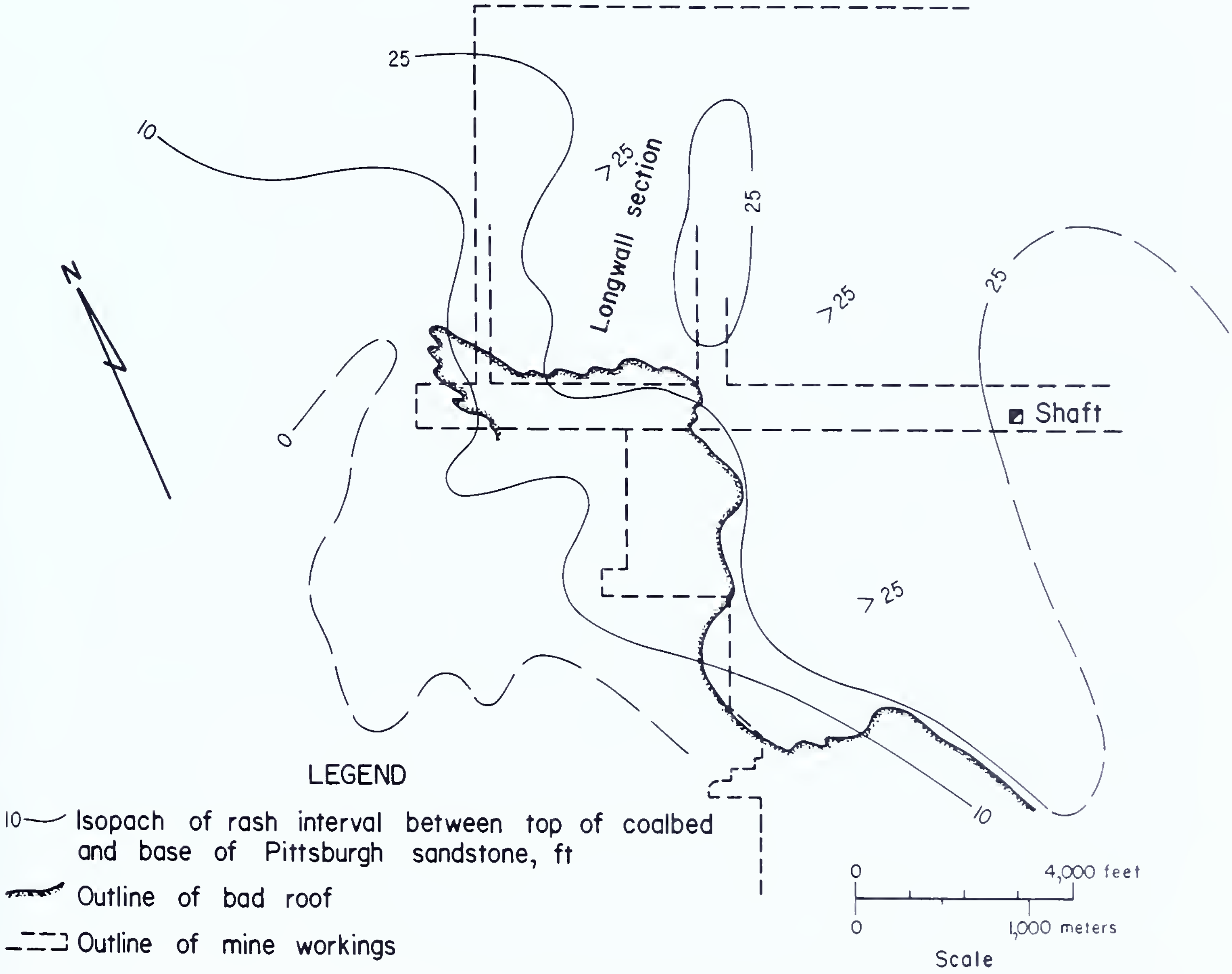

FIGURE 20. - Isopach of rash member in relation to area of bad roof conditions in West mains.

The probability that bad roof conditions will be encountered increases where the coal-sandstone interval is 10 to 25 feet. In the mine both good and poor roof conditions were observed where the interval was 0 to 10 feet and the immediate roof consisted chiefly of sandstone. Much depends on the mechanical properties of sandstone, the lithology, and the presence or absence of scours and channels in the basal portion. While none of this information was available from the exploratory drilling, the isopach map alone does provide one means of assessing potential roof instability. A geologists' log of the drill core and simple mechanical property tests can supplement the data. While the customary wide spacing of drill holes further limits prediction of roof instability to a low level of precision, the use of isopach maps in paleostream analysis in more accurately reconstructing the geometry and lithology of channel sandstones from drill core data could substantially increase this precision.[8]

For example, in figure 21, which portrays the entire mine area, the isopachs suggest northwest progradation by a distributary channel complex in the lower delta plain environment. The channel complex in the West mains area consists of two northeast-trending lobes of thick sandstone, one at 5 North and another at the face, each representing the distributary channels which carried the sand into the shallow bay. This environment is characterized by thick sandstones, basal scour, and abandoned stream channel deposits of siltstone or sandstone; thus irregular roof structure can be expected wherever the uneven base of the sandstone occurs within 25 feet or so of the coalbed. In contrast, an isopach map showing a thin sandstone bed with wide lateral continuity probably is devoid of channel or scour structures. Further inferences of rock texture and strength are possible if good logs are available.

While drill core data and isopach map analysis techniques are inadequate for predicting individual channel structures with precision, careful examination of cuttings or core from underground test holes drilled at least 10 feet into the mine roof at regular intervals might detect the sharp dip towards the face of the overlying sandstone-rash contact that is characteristic of channel margins. This would indicate that a channellike structure lay a short distance ahead of the face, thus warning of a potentially hazardous condition that must be given special attention.

Actual mining conditions encountered in the longwall section of the mine adjacent to the West mains also confirm the usefulness of isopach maps in assessing ground control where complete extraction is practiced. Figures 19 and 20 illustrate the general character of the roof strata over the longwall section north of the West mains. Figure 20 shows that roof over most of the section consists of 25 or more feet of the incompetent rash member which falls quickly as the longwall supports are advanced, thus avoiding an excess load on the supports by cantilevered roof strata. Also, the thickness of the rash indicates that massive competent beds only occur higher in the section, where hazards from overriding pressures and hanging roof are unlikely. Figure 19 shows that over most of the section the sandstone stratum above the rash is 10 feet or less in thickness and probably will cave readily during extraction rather than bridge the panels and contribute to excess loads on the headgate and tailgate pillars. The successful operation of shield-type roof supports in the longwall section confirms that the geological evidence summarized by the isopach maps was indeed favorable for complete extraction of coal by this method of mining.

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[8] Donaldson, A. C. Some Appalachian Coals and Carbonates: Models of Ancient Shallow-Water Deposition. W. Va. Geol. and Econ. Survey, W. Va. Univ., November 1969, pp. 93-105.

Ferm, J. C., J. J. Ketz, and R. A. Melton. Geological Contributions to Coal Mine Planning. Pres. at Ann. Meeting Geol. Soc. America, Salt Lake City, Utah, Oct. 20-22, 1975; Geol. Soc. America Abs., v. 7, No. 7, September 1975, p. 1072.

IN SITU STRESSES

To properly assess the geologic structures and their relation to roof conditions, it is necessary to consider the possibility that in situ stresses also might be a factor in roof stability and should be considered in the prediction of roof instability in advance of mining. In the West mains the evidence is conclusive that the geologic structures were the chief cause for the poor roof encountered beyond 5 North; however, some criteria were available with which to assess the area for the probable existence of high lateral in situ stresses.

Despite an almost total lack of reliable field data on the direction and magnitude of in situ stresses encountered in coal mining in the northern Appalachian Region, circumstantial evidence is abundant that in some situations severe roof instability is caused by high lateral in situ stresses. In southwestern Pennsylvania there is ample evidence that a high percentage of roof instability occurs beneath stream valleys, and there is a high degree of correlation between topographic valleys and roof failure. Over 90 percent of severe roof instability in this region occurs beneath stream valleys to a depth of about 600 feet. It is most common in north-south trending valleys. Below a depth of 600 feet, the effect diminishes rapidly. This instability is attributed to concentrated lateral stresses developed during overburden removal by erosion. Ferguson[7] described valley bottom deformation and fracturing caused by stress relief in the Allegheny Plateau in almost all major engineering projects that incise the valley sides and bottom. Thus valley or notch effect results in the so-called snap top in numerous coal mines in the region. (The term "snap top" originates from the audible snapping sound emitted by highly stressed roof rock shortly after exposure by mining.) The adverse effects of these stresses on mine roof generally begin as a cutter, or shear, where the roof and rib intersect, followed by roof deflection and additional development of cracks in the roof. The cutters

---

[7] Ferguson, H. F. Valley Stress Release in the Allegheny Plateau. Assoc. Eng. Geol. Bull., v. 4, No. 1, January 1967, pp. 63-69.

_____. Geologic Observations and Geotechnical Effects of Valley Stress Relief in the Allegheny Plateaus. Pres. at Ann. Meeting, ASCE, Los Angeles, Calif. Jan. 22-27, 1974, 31 pp.; available for consultation at Bureau of Mines, Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.

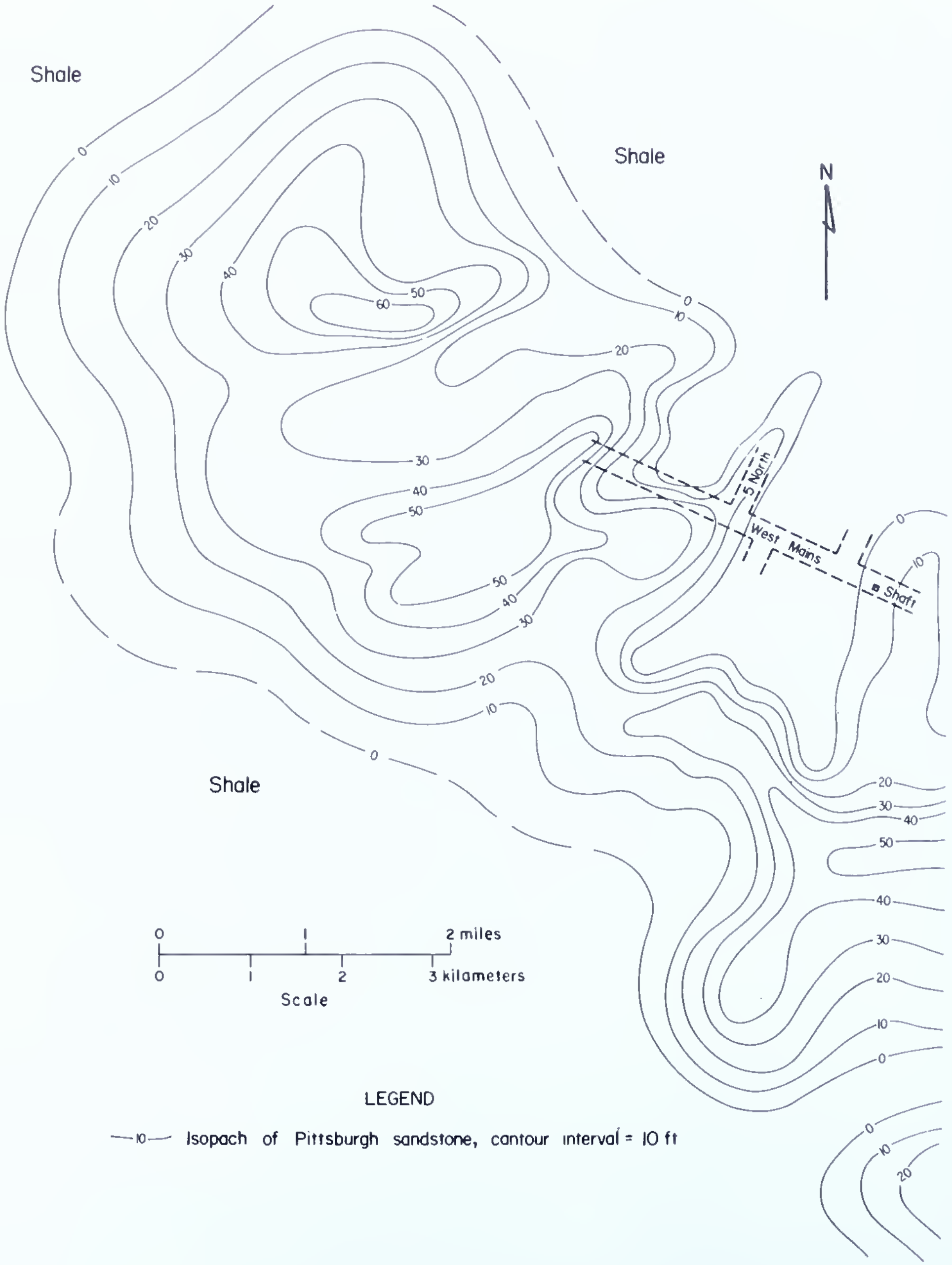

FIGURE 21. - Isopach of Pittsburgh sandstone.

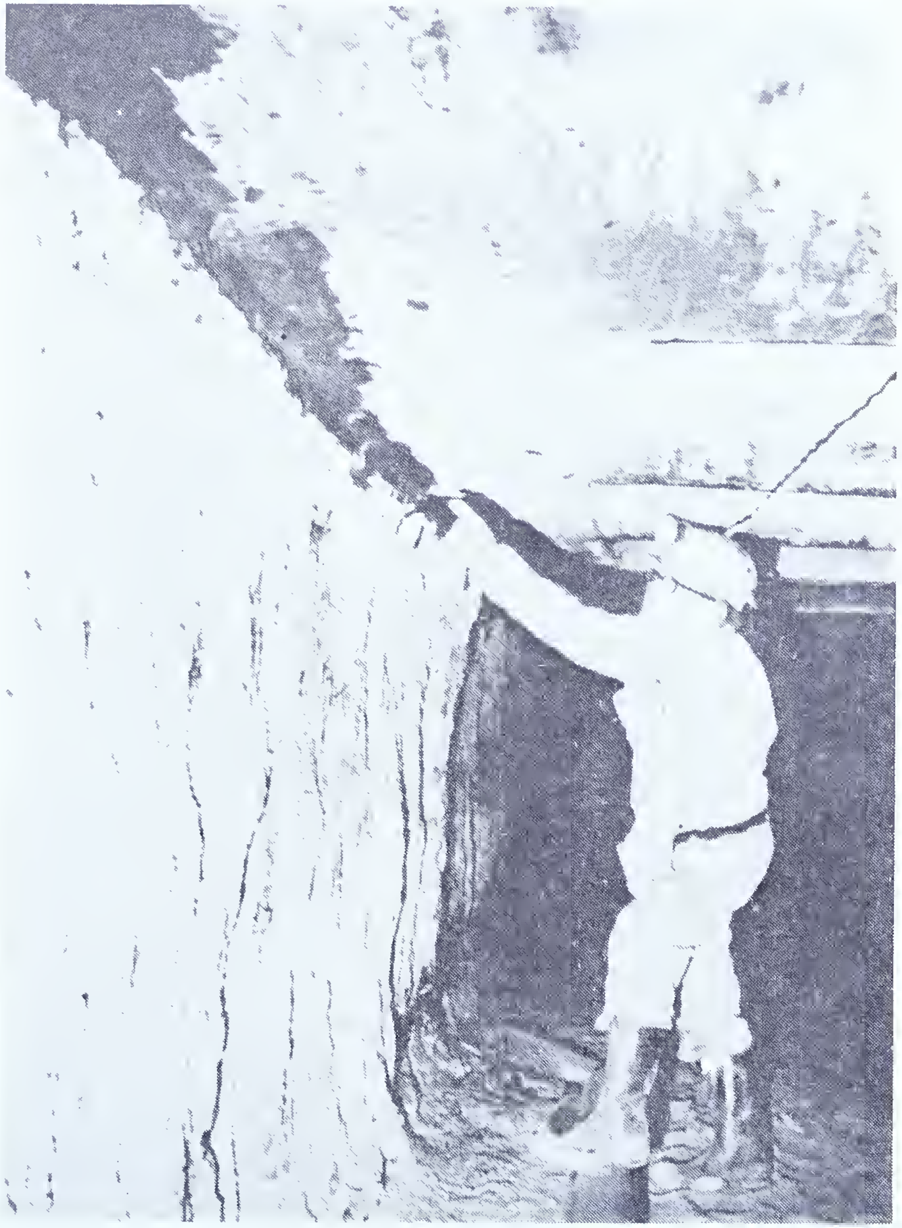

FIGURE 22. - Roof cutter indicative of high lateral stress.

usually develop within a few days of mining. Commonly, only heavy timber sets and cribs will prevent complete roof failure in zones of severe snap top (fig. 23). When failure occurs, the fall usually is high and breaks along the steeply dipping shears (fig. 24).

At the Gateway mine, the West mains were driven in a direction almost directly beneath the course of Ruff Creek. Figure 25 shows that the thickness of overburden ranged from 500 feet at the valley floor to nearly 800 feet under the hilltops. The stream valley is broad, and the valley walls slope gently, as compared with other localities in this region where severe roof problems occur directly beneath steep-walled valleys with high relief. The broad configuration of the Ruff Creek valley, moderate relief, and mining depth of 500 to 800 feet probably explain why high lateral in situ stresses were not troublesome in the West mains. This is confirmed by the general absence of the characteristic roof cutters associated with snap top. Thus, the overburden isopach map could have contributed to a prediction of potential roof conditions in the West mains by showing that the overburden and valley configuration were not characteristic of a snap-top zone in which high in situ stresses can be expected to cause roof instability.

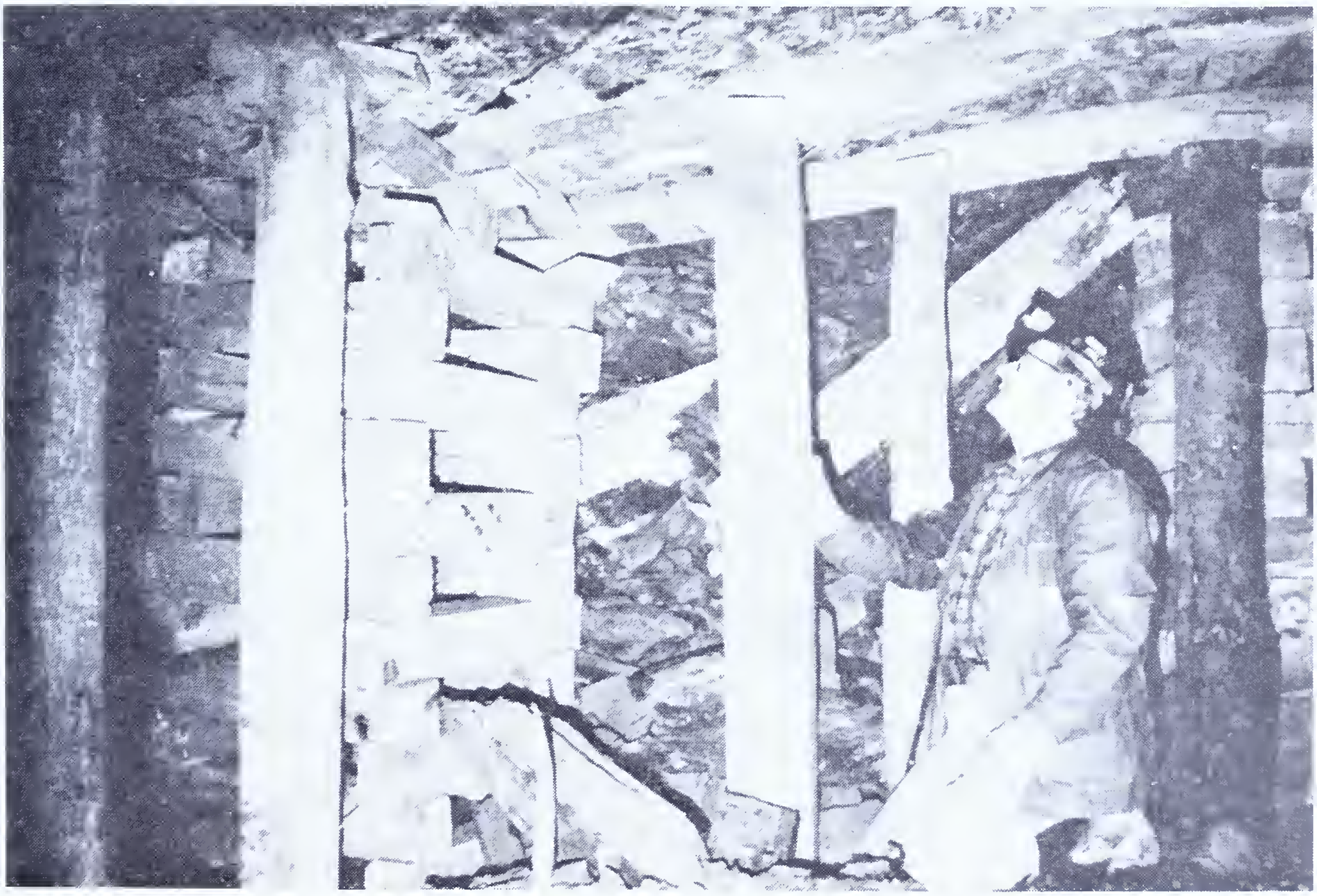

FIGURE 23. - Supplementary support near edge of severe snap-top zone.

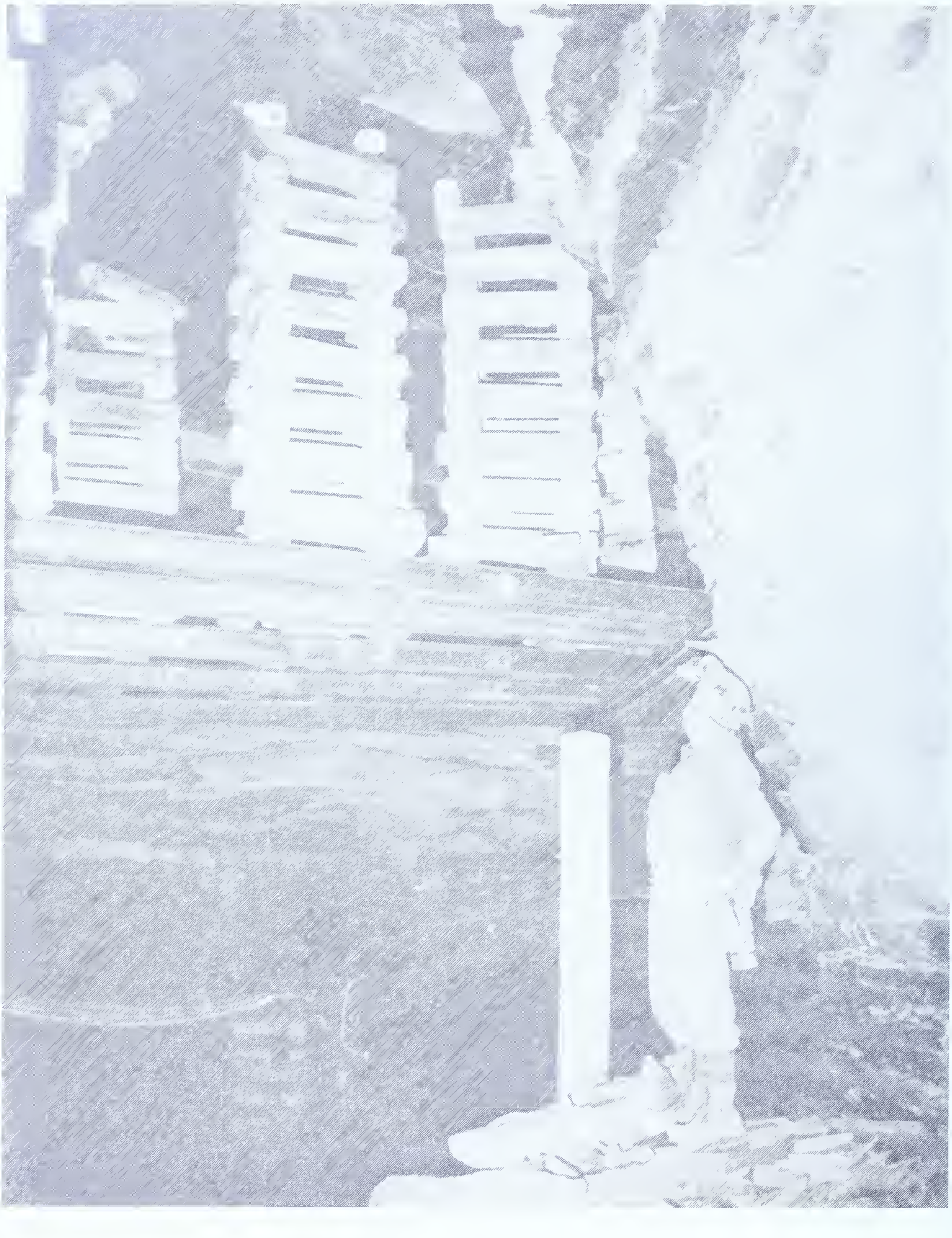

FIGURE 24. - Roof fall in highly stressed snap-top zone.

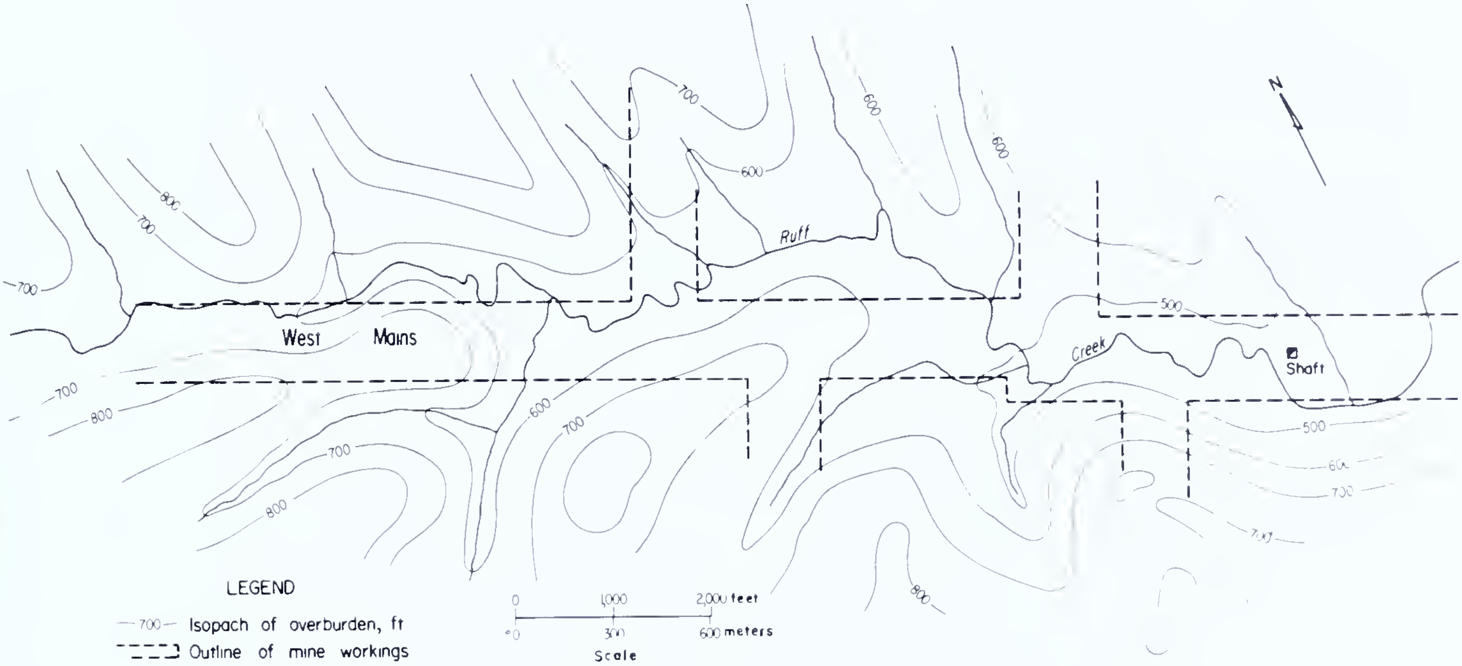

FIGURE 25. - Isopach of mine overburden along West mains.

CONCLUSIONS

The analysis of geologic data compiled during this study leads to the following conclusions:

1. Severe roof problems in a portion of the West mains of the Gateway mine were due chiefly to the presence of weak slickensided zones beneath small sandstone-filled channels and scours.

2. The existence of these structures could be inferred from exploratory drill core logs and sandstone isopach maps prepared from these logs.

3. The immediate roof, consisting of varying thicknesses of interbedded coal, claystone, and clay shale, called rash, had very low mechanical strength--generally too low to withstand coring and testing. However, this material was successfully supported when it was laterally continuous and devoid of irregular structures or large slickensides.

4. Roof problems can be anticipated where the sandstone in the immediate or main roof consists of weakly cemented grains and is flaggy because of shaly or micaceous partings or trashy with coal laminae.

5. Severe roof problems were not encountered either marginal to or beneath broad washouts in the coalbed at this mine; therefore, their presence is of little value as an indicator of unstable roof.

6. After allowance is made for the improved roof structure in the western portion of the West mains, resin bolting shows only a modest improvement in effectiveness of supporting mine roof over the tension bolting used previously.

7. Roof cutters caused by high lateral in situ stresses, usually concentrated beneath stream valleys, were not detected in the West mains, and the absence of stress-related snap top could be inferred from a map showing the thickness of the overburden.

8. Underground personnel usually are unaware of the nature and geometry of the complex geologic structures in mine roof rock. Some improvement in roof support technique and safety might result from instructing them in ways to recognize these features.

APPENDIX

Mining Equipment

Continuous miners: Lee Norse, 38 J, Joy 1 cm, Joy 8 cm, Joy 10 cm.

Haulage Equipment

Belt conveyors for sectional and main haulage; Joy 10 S.C. and Torkar shuttle cars for face haulage; track for men and supply transportation.

Longwall Equipment

Eickhoff double-drum shearer, model EDW 200-L 440V, 52-inch-drum diameter 30-inch-drum-width, Klockner Ferromatik shields with two double-acting legs, each rated to yield at 176 tons under pressure of 5,925 psi.

Mechanical Roof Bolts

Bolts:	
Length (minimum)........................feet..	4
Diameter...............................inches..	5/8 and 3/4
Composition...................................	High-strength steel, ASTM A-306, Grade 80
Thread type...................................	Rolled
Length of thread (minimum)..........inches..	5
Head type.....................................	Standard, 1-1/8-inch square
Flange size...........................inches..	1-5/8 to 2
Bearing plates:	
Shape...	Embossed, bell and elliptical bell
Dimensions............................inches..	1/4 by 6 by 6, 1/4 by 6 by 18
Center hole............................inch..	11/16
Anchorage unit:	
Type..	2- and 3-leaf modified bail
Size of hole..........................inches..	1-3/8
Method of drilling............................	Rotary percussion and percussion
Installed torque......................ft-lb..	120-160 (5/8-inch diam) 200-250 (3/4-inch diam)
Materials used in conjunction with roof bolts.	Head blocks and wood planks

Alternative Roof Support

Penn-Birmingham "Roof Trusses" used for additional roof support.

Posts:		
Length	feet	6, 8, and 10
Diameter (minimum)	inches	5
Type		Round, untreated hardwood
Cap blocks	inches	5 by 16 by 2
Wedges	do	5 by 12 by 1, tapered to 0
Crossbars:		
Wood		5 by 7 inches by 14 feet 6 by 18 inches by 16 feet 7 by 9 inches by 18 feet
Aluminum		6-inch-wide flange H-beams of various lengths
Steel		6-inch and 8-inch-wide flange H-beams of various lengths
Cribbing blocks:		
Hardwood		Treated and untreated
Dimensions	inches	4 by 5 by 30

Resin-Grouted Rods

Rods:		
Manufacturer		Dupont Birmingham Bolt
Length (minimum)	feet	5
Diameter	inch	3/4
Composition		High-quality steel
Yield (minimum)	psi	43,000
Head		1-1/8-inch-square by 1/2 inch integral forged
Flange		1-7/8 by 1/8 inch integral forged
Bearing plates:		
Shape		Embossed
Dimension	inches	6 by 6
Center hole diameter	inch	1
Resin:		
Manufacturer's designation		Fasloc (Dupont)
Type		Fast set in cartridges
Method of drilling		Rotary
Finishing bit size	inches	1±0.030

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977-703-001/66

INT.-BU.OF MINES,PGH.,PA. 22172

Report of Investigations 7769

Geologic Factors Causing Roof Instability and Methane Emission Problems

The Lower Kittanning Coalbed, Cambria County, Pa.

by C. M. McCulloch and Maurice Deul
Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.

MARCH 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

BUREAU OF MINES
Elburt F. Osborn, Director

This publication has been cataloged as follows:

McCulloch, Charles M

Geologic factors causing roof instability and methane emission problems: the Lower Kittanning coalbed, Cambria County, Pa., by C. M. McCulloch and Maurice Deul. [Washington] U.S. Bureau of Mines [1973]

25 p., illus., tables. (U.S. Bureau of Mines. Report of investigations 7769)

Includes bibliography.

1. Coal mines and mining—Pennsylvania—Cambria County. I. Deul, Maurice, jt. auth. II. U.S. Bureau of Mines. III. Title. (Series)

TN23.U7 no. 7769 622.06173

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GEOLOGIC FACTORS CAUSING ROOF INSTABILITY AND METHANE EMISSION PROBLEMS

The Lower Kittanning Coalbed, Cambria County, Pa.

by

C. M. McCulloch[1] and Maurice Deul[2]

ABSTRACT

A geologic study of Mines 32 and 33 in Cambria County, Pa., was conducted as part of a methane control research program. Areas of high methane emission and roof instability are encountered which are related to the structural and stratigraphic features that characterize the geologic setting of these mines. Locally the folds trend N 20° E ±2°, the direction of the butt cleat in the Lower Kittanning coal. The face cleat strikes at N 69° W ±2° and the systematic rock joint in the surface bedrock strikes N 67° W ±2°. This suggests that a directional stress oriented N 70° W produced the folds and influenced the directions of coal cleat and systematic joint sets. Analysis of SLAR indicates three directions of prominent regional lineation: N 39° E, N 31° W, and N 70° W.

Little gas was encountered during development mining; large volumes of gas are encountered when roof falls. Most of the gas comes from strata above the mined coal; therefore, to control methane, roof instability must be controlled.

Roof falls and high rates of methane emission are most likely where less than 30 feet of many thin layers of limestone, shale, and sandstone occurs between the Lower Kittanning coal and the next coal and in zones along the margins of a sandstone channel.

INTRODUCTION

The Cambria Nos. 32 and 33 mines are located in western Pennsylvania near Ebensburg, about 60 miles east of Pittsburgh. The No. 33 is a slope mine, whereas the No. 32 is a shaft-type mine; both are presently working beneath 300 to 1,000 feet of cover in the Lower Kittanning coalbed. Data on the compass directions of joint sets and coal cleats, together with regional structure and stratigraphic observations, were analyzed for indicators of geologic control of the emission of methane from the coalbed into the mine workings, and of relationships to roof falls in the mines.

Geologist.

Supervisory geologist.

This project was conducted as part of the methane control research program to determine the cause of the large amount of methane being emitted into the mine workings. Areas of large methane emissions were found to be areas of roof instability. Therefore, for these mines, studies of roof instability were a natural consequence, although not the original objective.

ACKNOWLEDGMENTS

We acknowledge the cooperation and assistance of the management of Bethlehem Mines Corp. with whom we have held cooperative agreements for many years. Special thanks are due to personnel of the Cambria division for their personal interest and support, notably A. T. Sossong, the division engineer. We acknowledge the assistance of Lou Benedict from the Bethlehem Research Center for the time and effort he devoted in the field and for his critical comments. We also thank Bion Kent of the U.S. Geological Survey for his critical review and many thoughtful suggestions.

PREVIOUS AND CONCURRENT WORK

The first geologic work in the Cambria County area was done by H. D. Rogers in 1858 (15),[3] who conducted the first geologic survey of the entire State of Pennsylvania. In 1877, F. Platt and W. G. Platt (14) did a geologic study of the Cambria and Somerset districts. Both these reports were excellent and have been updated recently.

In 1905, Charles Butts (3) completed the next major work on the Cambria County area with his "Ebensburg Portfolio," a geologic study of the Ebensburg 15-minute quadrangle that included a structure map drawn on the Upper Freeport coalbed. The stratigraphy of the area was described in that report but the group, formation, and member names of some of the units have been changed.

Ashley, Sisler, and Reese (1), 1925-1928, of the Pennsylvania State Geological Survey wrote a report on the "Bituminous Coal Fields of Pennsylvania." This was a description of individual coalbeds, coalfields, and a summary of resources of Pennsylvania.

Dutcher (5) produced a field trip guide to this general area for the Pittsburgh meeting of the Geological Society of America.

Concurrent work in the Cambria County area is being done by Lou Benedict of Bethlehem Steel Corp. on some of the same problems dealt with in this paper. His results to date agree generally with the findings of this report even though his techniques are somewhat different.

STRATIGRAPHY

Only the Allegheny group of the Pennsylvanian system will be discussed since all the coalbeds that are important to this study are included within it.

---

[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

The Allegheny group extends from the base of the Brookville coal to the top of the Upper Freeport coal (8). The average thickness in Cambria County is approximately 250 feet. This group is composed of shale, siltstone, sandstone, coal, and some fresh-water limestone lenses found in the upper third of this group. Flint (8) states that the Johnstown limestone is persistent and is used as a stratigraphic guide in Somerset County to the south. In the surface area around Ebensburg, where this study was conducted, and from core hole data, this limestone, although less persistent, is still found in 10 of the core holes.

The Allegheny group is subdivided into three formations following Shaffner (16) and Williams (17). These are Clarion, Kittanning, and Freeport. The boundary between the Clarion and Kittanning formations falls within the Lower Kittanning coal group. The Kittanning formation (18) is made up of

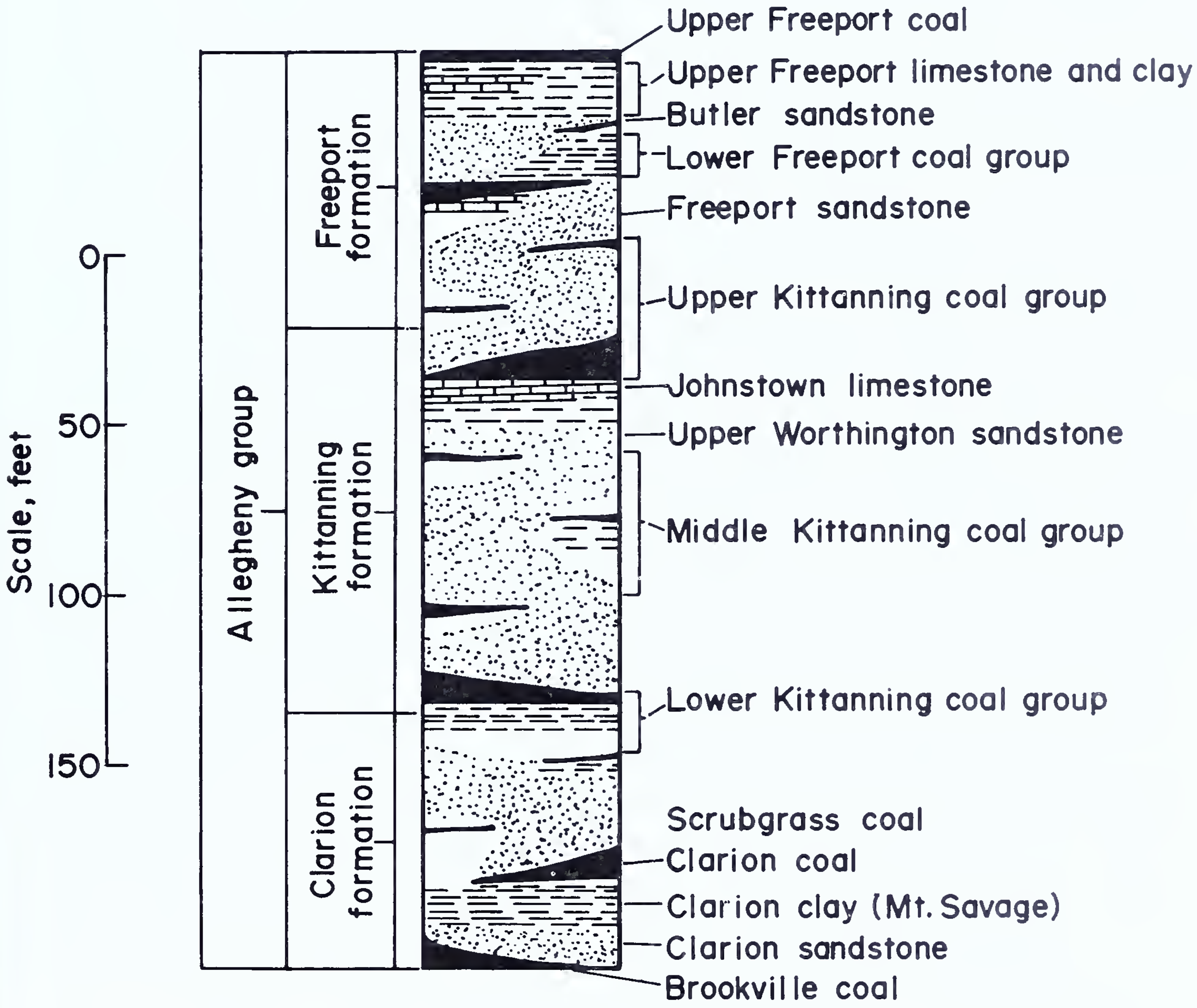


FIGURE 1. - Generalized section of the Allegheny group of the southern part of Somerset County, Pa.

"strata between the base of the underclay beneath the upper coalbed of the Lower Kittanning coal group and the top of the lower bench of the Upper Kittanning coal group." The average thickness of this sequence determined from the core hole data in this report is 106 feet. The persistent sandstone that overlies the Lower Kittanning coalbed is the Worthington Sandstone (14).

The three Kittanning coalbeds have alternate letter designations. They are sometimes referred to as follows:

Lower Kittanning coalbed--"B coal"
Middle Kittanning coalbed--"C coal"
Upper Kittanning coalbed--"C prime coal"

The Johnstown limestone, the most persistent limestone in the area, is found underlying the Upper Kittanning coalbed.

Of the two stratigraphic columns shown, the first (fig. 1) is the "generalized section of the Allegheny group of southern Somerset County, Pa." (8). A stratigraphic column of the Kittanning formation of the area considered in this report (fig. 2) has been drawn from core hole data and underground fall areas observed in the mines; this uses Flint's terminology.

REGIONAL AND LOCAL STRUCTURE

The Cambria Nos. 32 and 33 mines are located in the area where the main structures are the Ebensburg anticline and the Wilmore syncline (fig. 3). These features are part of the Allegheny Mountain section of the Appalachian Plateaus province and trend northeastward.

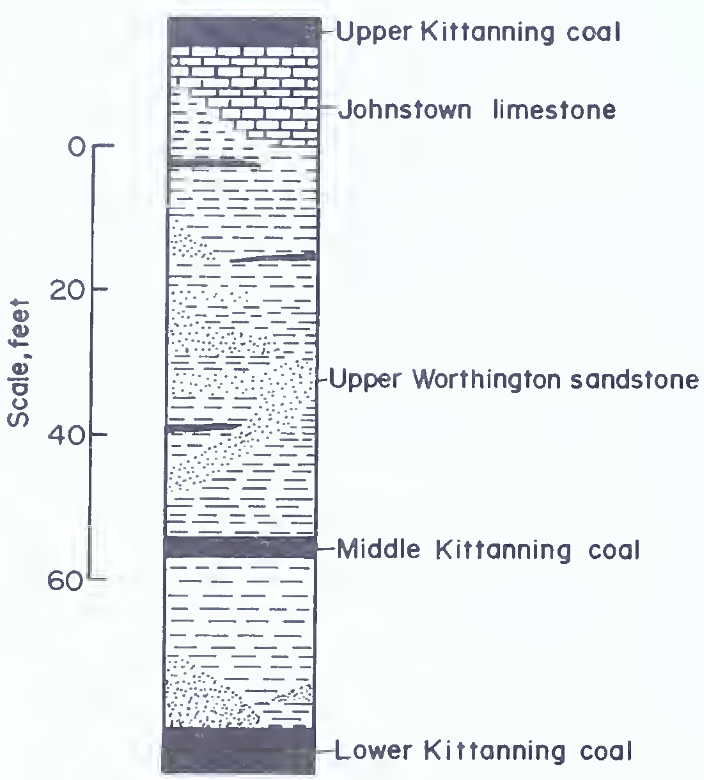


FIGURE 2. - Generalized section of the Kittanning formation of central Cambria County, Pa.

The structural contours in figure 3 were drawn on the bottom of the Lower Kittanning coalbed from mine and core hole data.

SLAR Imagery

The SLAR (side look airborne radar) imagery was used to supplement the fieldwork and computer treatment of field data. The main utility of SLAR imagery is that it permits systematic examination of large areas making it possible to note subtle topographic differences (lineations, faults, etc.) over long distances that would have been missed by normal geologic methods (4, 10).

The interpretation of the SLAR imagery is similar to that used in

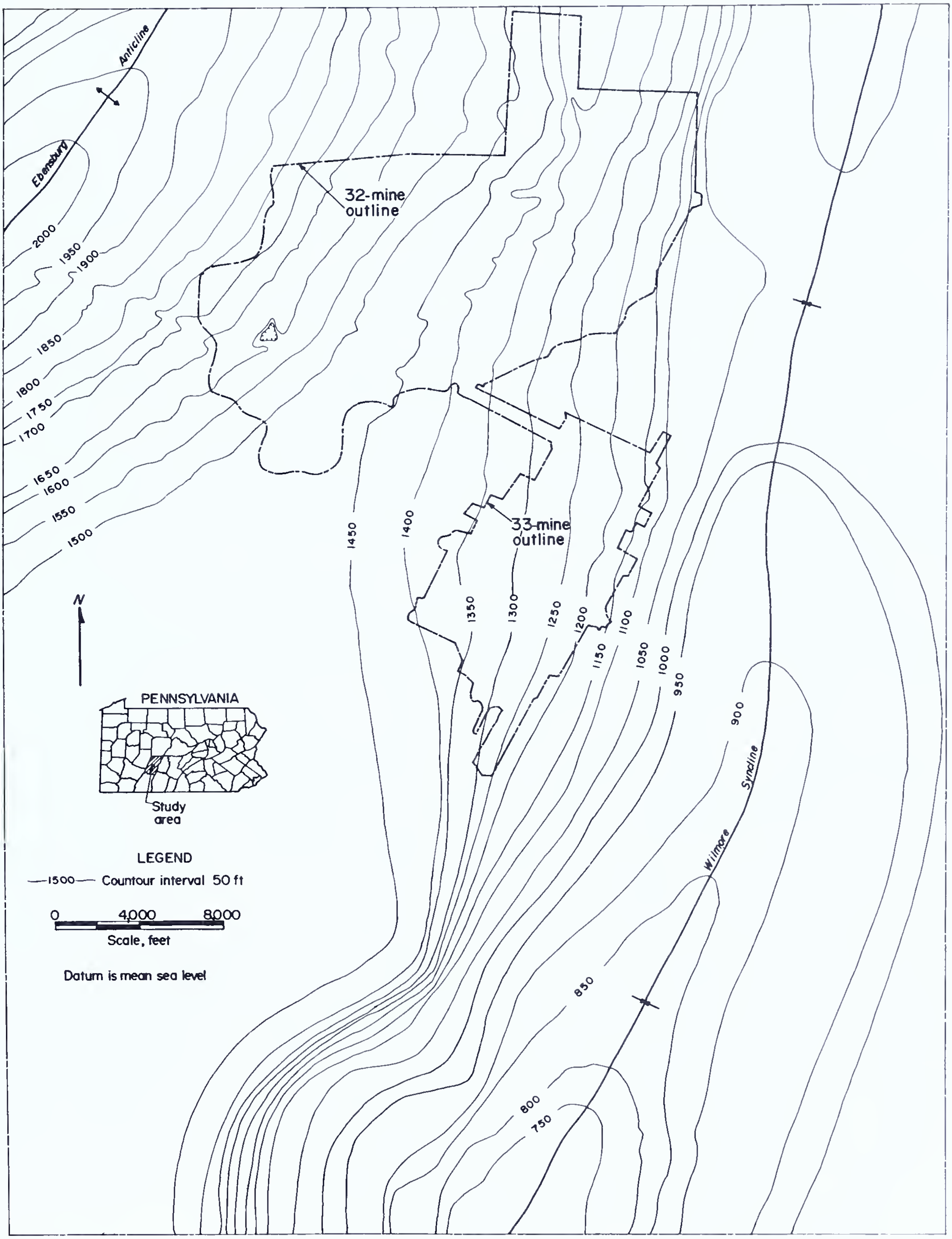


FIGURE 3. - Generalized structural contour map of area around Cambria Nos. 32 and 33 mines.

standard photogeologic interpretations. A Ronchi grating (a type of diffraction grating) can be used between the eye and the imagery; when rotated, strong lineations will become easily visible. The grating is to SLAR what stereographic glasses are to paired aerial photographs.

SLAR imagery was adjusted for true distances and directions from geological reconnaissance studies. According to MacDonald (12), "This computation can be accomplished most easily where a known distance between two points on the ground can be compared with the same two points on the radar imagery."

SLAR imagery of Cambria County, Pa., was studied for this report. Three prominent directions of lineations were observed on the SLAR imagery; these are (1) N 39° E, (2) N 31° W, and (3) N 70° W. These directions are indicated on figure 4.

Rock Joints and Coal Cleats

The strike and dip of the coal cleats and the surface rock joints were measured. The orientations of the various cleat and fundamental joint system directions are shown in figure 5. Nickelson (13) divided the fundamental joint system into two parts: (1) systematic joints and (2) nonsystematic joints.

According to Nickelson (13), "The complex pattern of jointing results from overprinting of two or more fundamental systems" with the systematic joint having well-defined axes whereas the nonsystematic joints are poorly defined.

From table 1 the average strike for the face cleats of the coal is N 69° W, whereas the average strike for the systematic surface rock joint is N 67° W, including the measurements of rock joints at location 4 in figure 4. The strikes of the two features are about the same, suggesting that there is a relationship between the strike of the systematic rock joints and the coal face cleats.

TABLE 1. - Average strike of coal face cleat and systematic rock joints

	Measurements	Strike[1]
Coal face cleat..................	1,725	N 69° W
Systematic rock joints..........	159	N 69° W (1)
Do..........................	332	N 69° W (2)
Do..........................	195	N 68° W (3)
Do..........................	189	N 58° W (4)
Do..........................	170	N 66° W (5)
Total.................	1,045	

[1] Number in parentheses corresponds to position on index map. All are ±2° compass directions.

The general locations of surface joint measurements are shown in figure 4.

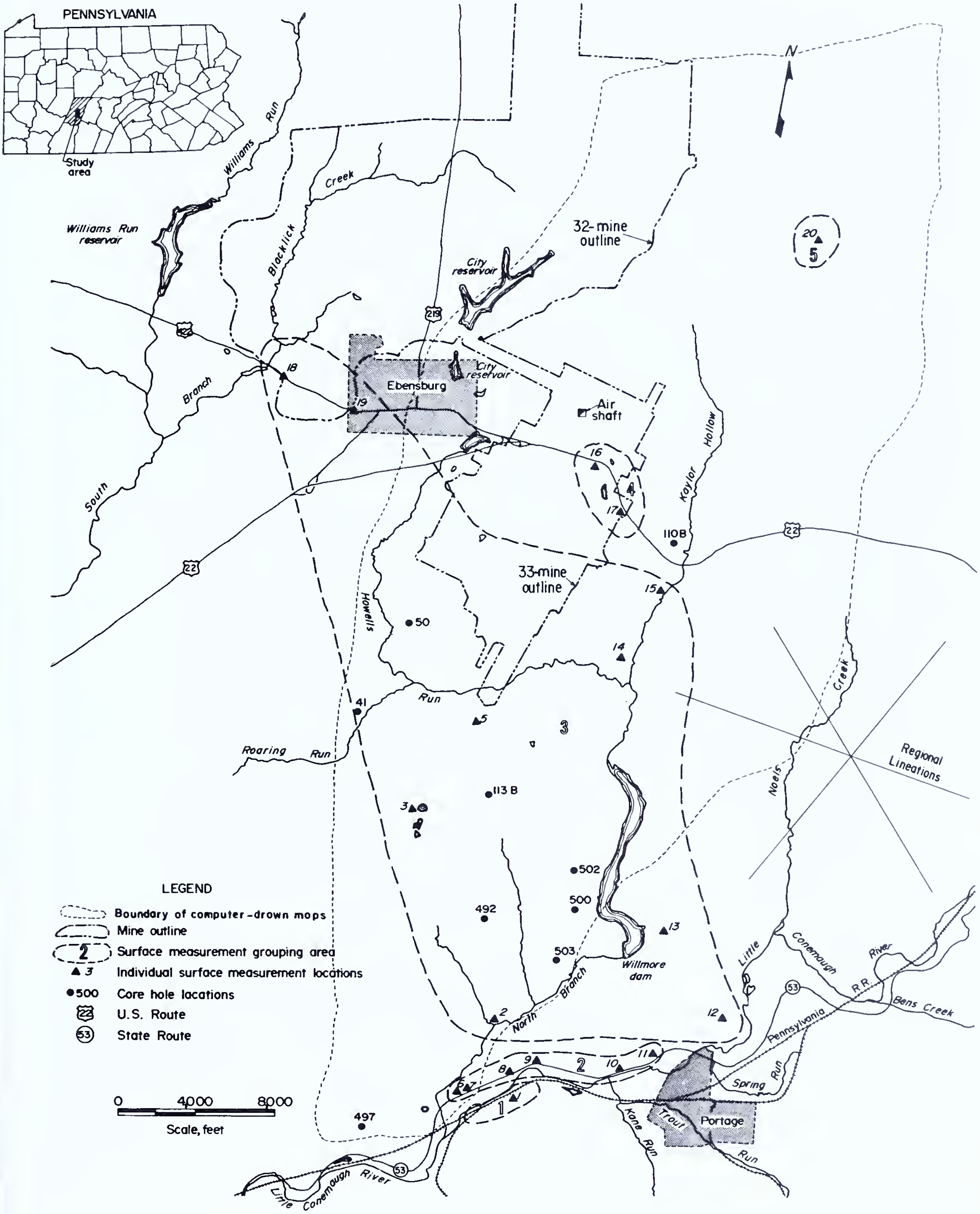
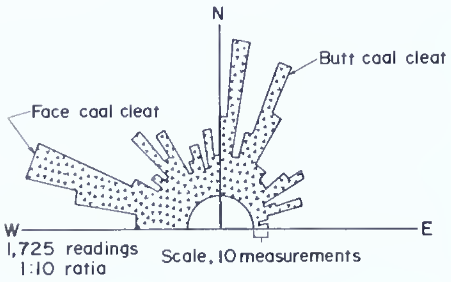
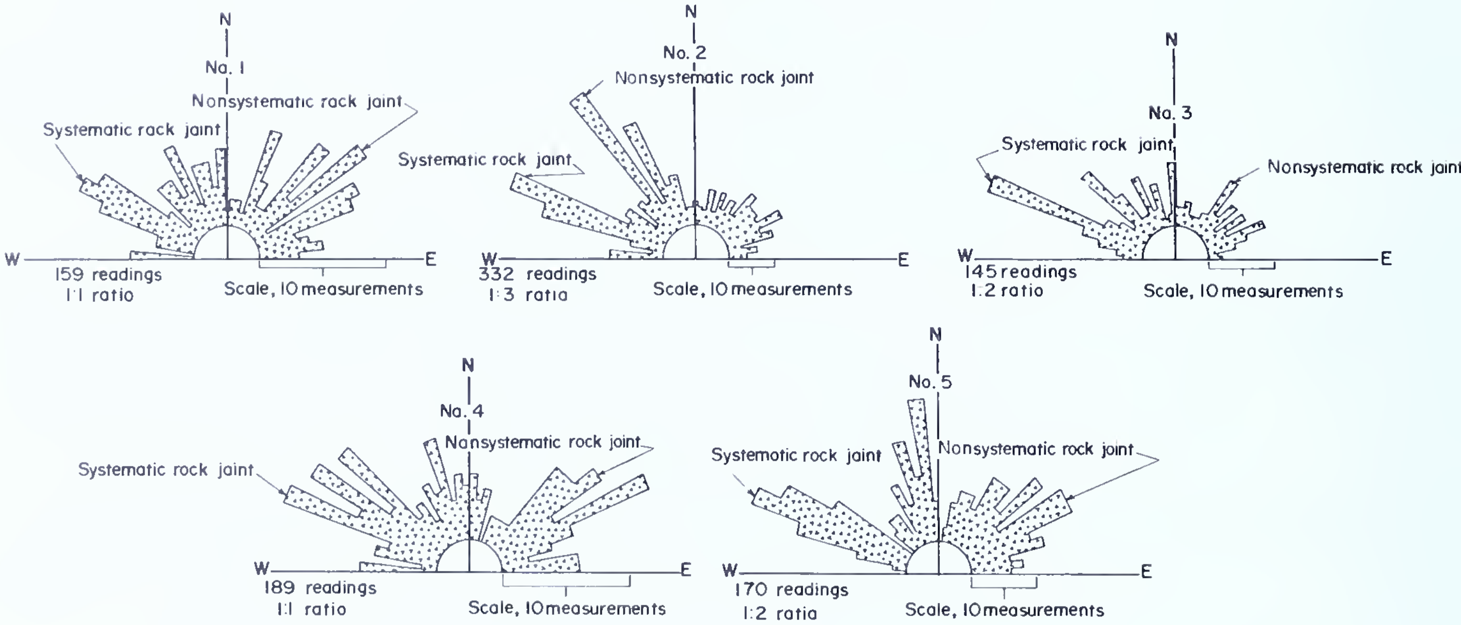


FIGURE 4. - Index map of surface joint sampling locations.



COAL CLEAT MEASUREMENTS



ROCK-JOINT MEASUREMENTS

FIGURE 5. - Strike of coal cleats and rock joints.

Measurements at location 4 were made at sites where we found later there had been major surficial dislocation either by slumping due to erosion of adjacent stream valleys or to caving of underground workings. Comparing figure 4 with figure 6, it can be observed that "individual surface measurement locations" 16 and 17 are directly over areas where roof falls have occurred, supporting the idea that caving may be a factor in the deviation of these measurements from the norm. The computer program used to treat these data selected the center of a trimodal distribution as the strong direction rather than one of the extremes. Figure 5 illustrates the trimodal distribution at location 4. It appears that the lower of the three northwest lobes is the stronger but the difference is small. Field checks show that the most prominent direction is the one designated at location 4 as being the "systematic rock joint," N 68° W, very close in direction to the other four areas of surface measurement, but the other two lobes indicate some change or rotation and contribute to making the average direction N 58° W.

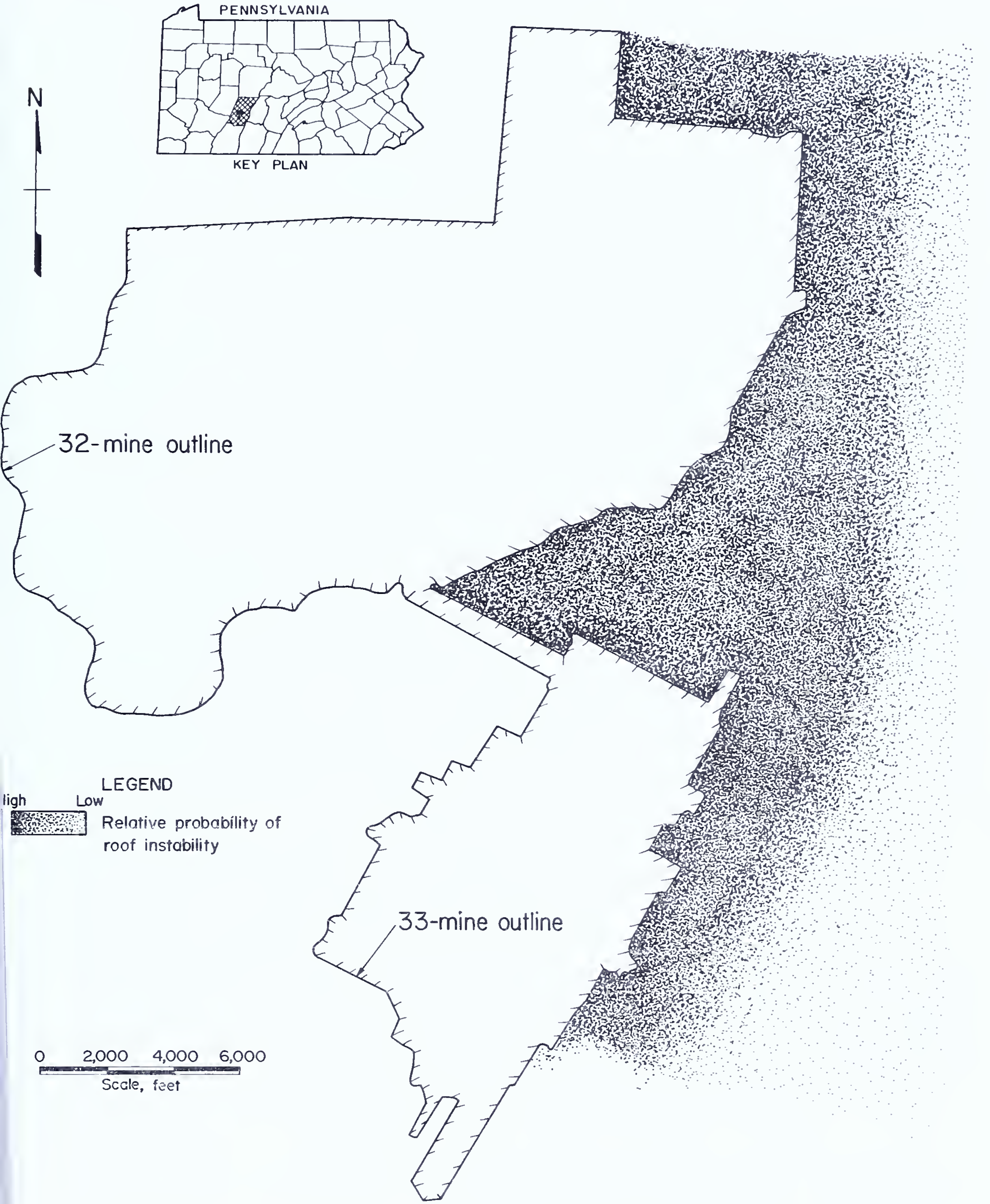


FIGURE 6. - Sketch map showing where unstable roof is likely to occur.

From table 2 the average strike for the butt cleat is N 19° E, and the average strike for the nonsystematic rock joint is N 04° W. As can be seen from the data, the variations in the nonsystematic joint measurements are too great to have any significance; this was also supported by the computer program printout.

TABLE 2. - Average strike of coal butt cleat and nonsystematic rock joints

	Measurements	Strike[1]
Coal butt cleat....................	1,725	N 19° E
Nonsystematic rock joints..........	159	N 52° E (1)
Do............................	332	N 38° W (2)
Do............................	195	N 50° W (3)
Do............................	189	N 68° W (4)
Do............................	170	N 62° E (5)
Total....................	1,045	

[1] Number in parentheses corresponds to location on index map. All are ±2° compass directions.

There is a relationship between the axial direction of the local folds and the strike of the butt cleats. The local fold axes range from N 35° E to N 12° E but mostly between N 17° E and N 22° E, nearly the same as the average butt cleat direction of N 19° E. Figure 5 shows a relationship between the coal face cleat and systematic rock joint direction but shows no relationship between the coal butt cleat and nonsystematic rock joint direction.

This is a summary of the strikes of the coal cleats and rock joints:

1. Strike of face coal cleat--N 69° W.

2. Strike of systematic surface rock joint--N 67° W.

3. Strike of butt coal cleat--N 19° E.

4. Strike of nonsystematic surface rock joint--N 04° W.

From this it is evident that there is a parallelism between the N 70° W major regional lineation, the face coal cleat, and the systematic rock joint. No relationship is evident between any of the three major regional lineations determined from SLAR imagery and the butt cleat or nonsystematic rock joint strikes.

Methane Emission in the Cambria Mines

Underground, in the Cambria Nos. 32 and 33 mines, water seepage and methane emission from the roof is observed along prominent fractures that trend N 70° W, a direction that parallels the systematic joint sets, the coal face cleats, and the major regional lineations.

The amount of gas emitted directly from the Lower Kittanning coal into the mine working is known to be small. Upon development of mine workings and in preparation for installation of longwall mining equipment, methane emission rates are very low. In one methane emission study in a development section, only 23 cfm of methane was measured. In contrast, when longwall mining is being conducted, methane emission rates rise to more than 800 cfm from a single section (11). Normally, in these mines, most of the methane emission occurs when retreat longwall mining induces roof falls with subsequent methane accumulation in the gob. Methods of removing this methane have been described by Elder (6) and by Ferguson (7).

Methane emission rates from all the principal coal mines of the United States are listed in a report by Irani (9). These reported data do not include the amounts of methane removed from gobs by vertical boreholes.

Because methane occurs in the strata immediately above the Lower Kittanning coalbed in these mines, unexpected roof falls are the main cause of high rates of methane emission in development sections. Consequently, methane control during development is best accomplished by controlling roof.

Bureau of Mines studies demonstrated that within any mine directional permeability does exist. The face cleat is the dominant cleat direction; because it has greater horizontal length and is usually better developed, one would expect to encounter more gas in mining perpendicular to the face cleat. This is a demonstration of directional permeability.

Two holes were drilled horizontally into the coalbed at N 65° W and N 25° E. The gas pressure along the N 65° W direction was 12.0 psi, whereas the gas pressure measured along the N 25° E direction was 30 psi. The direction of these measurements approximate the face and butt cleat directions, which average N 68° W and N 19° E. Because the face cleat is more continuous, it would be expected to yield more gas where transected; this is supported by the fact that the horizontal borehole drilled at N 25° E (almost parallel to the butt cleat) yields 2.5 times as much gas as the hole drilled parallel to the face cleat.

Roof Joints and Roof Falls

We have observed roof instability (1) where differential compaction and folding have occurred along the side of channel sandstone deposits, as along the east side of the Cambria 32 mine, and (2) where the sandstone has formed a sheetlike structure and numerous (greater than nine), thin lithologic units occur directly above the Lower Kittanning coal within an interval of 30 feet. Where the next coal above the Lower Kittanning occurs less than 30 feet above, and/or where the space between joints is less than 4 feet, roof instability is even more likely. Most of the roof falls observed showed coal in the upper part of the fall and the vertical interval was less than 30 feet.

Roof joints were measured underground where possible. Most (26 out of 35) ranged from between N 65° W to 73° W, roughly parallel to regional lineation of N 70° W (SLAR). The other nine readings were scattered, but at least two each mirrored the other regional lineations (N 31° W, N 39° E) as determined from the SLAR.

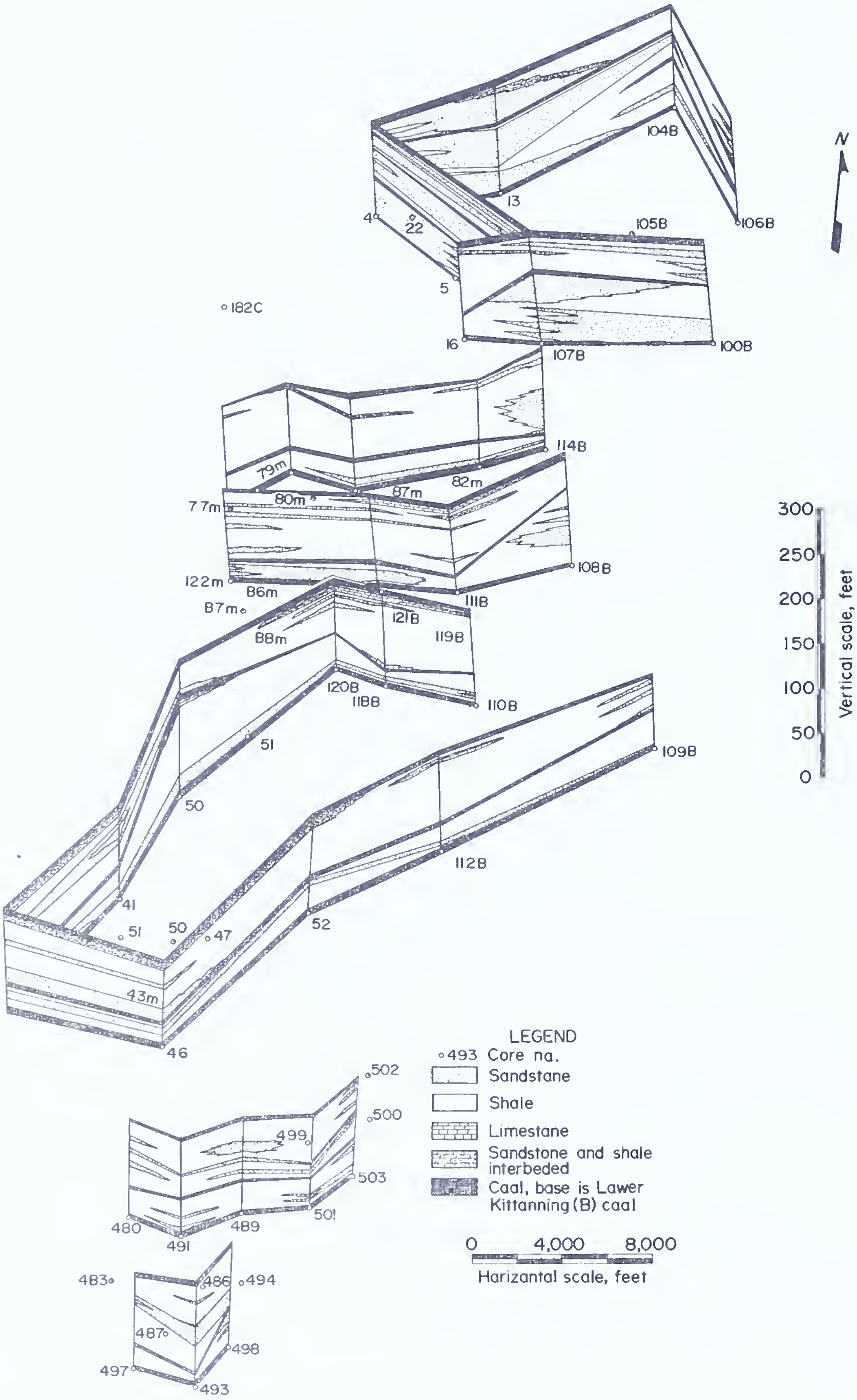


FIGURE 7. - Panel diagram of interval between Lower and Upper Kittanning coalbeds.

Jointing is not the sole cause of roof falls in these mines. It is a contributory factor. Where roof might have been stable under all other conditions a very close joint spacing contributes to unstable roof.

LITHOLOGIC VARIABILITY

Underground exposures and core log data show that the sandstone immediately above the Lower Kittanning coalbed occurs either as a channel fill deposit changing abruptly to shale or as sheetlike deposits which interfinger with shales.

To display the lithologic variability of this area, a panel diagram (fig. 7) was prepared from core logs using the interval between the Lower and Upper Kittanning coalbeds. In the north, sandstone is the predominant rock; southward, the shale becomes dominant. The panel diagram shows a channel area along the east margin of the mine that eventually broadens to form a sheetlike structure to the south and west.

As an aid to analysis of the sedimentation and to insure complete objectivity, the following maps were drawn by computer to indicate the following: lithologic frequency of the interval between the Lower Kittanning and Upper Kittanning coalbeds, lithologic frequency of the interval between the Lower Kittanning and the next higher coal, percentage of sandstone in coalbed area, percentage of shale in coalbed area, shale plus limestone to sandstone ratio, and the interval between the Lower Kittanning and the next higher coalbed. This was done by laying a grid over a base map of the core holes; these could be located by the computer program along X (distance in feet east of the starting point or zero point) and Y (distance in feet north of the zero point) coordinates. The X and Y values are used in the computer program only to locate the core holes on the map. The data to be plotted (the Z value) are selected from the core logs as required; for example, the percent sandstone for a given interval as in the maps indicating the percentage of sandstone, or the number of lithologic units as in the maps on lithologic frequency. The Z value is established for each core hole, and this value plus the X and Y coordinates are used in the computer program to plot a map using an appropriate contour interval. The X and Y coordinates are constant for all computer output maps, and only the Z value and the contour interval vary.

Lithologic Frequency

A lithologic frequency map (fig. 8) shows the number of separate lithologic units for a given interval. The interval is arbitrarily selected depending on the information to be illustrated. This lithologic frequency map was drawn using as contours the number of lithologic units occurring in the approximately 100-foot interval between the Upper and Lower Kittanning coalbeds. The number ranges from four to 24 lithologic units. A lithologic unit is defined here as any thickness greater than 0.5 foot in thickness.

One area showing an extremely large number of lithologic units, more than 20, and two other areas showing more than 15, were found. These areas coincide with known areas of roof instability in the mine. When conducting underground surveys in these areas of roof instability, it was noted that the joints in the roof were closely spaced and that the distance to the next coal above the Lower Kittanning was less than 32 feet wherever the roof had fallen. In contrast, a smaller number of thicker lithologic units would indicate relatively stable roof conditions.

The close proximity of zone of a very high and low number of lithologic units is an indication of rapid sedimentational changes and a site of potentially unstable roof.

Lithologic Frequency Between Lower Kittanning Coal and the Next Higher Coal

A low lithologic frequency indicates areas where relatively stable roof rock can be expected. Areas of intermediate lithologic frequency may or may

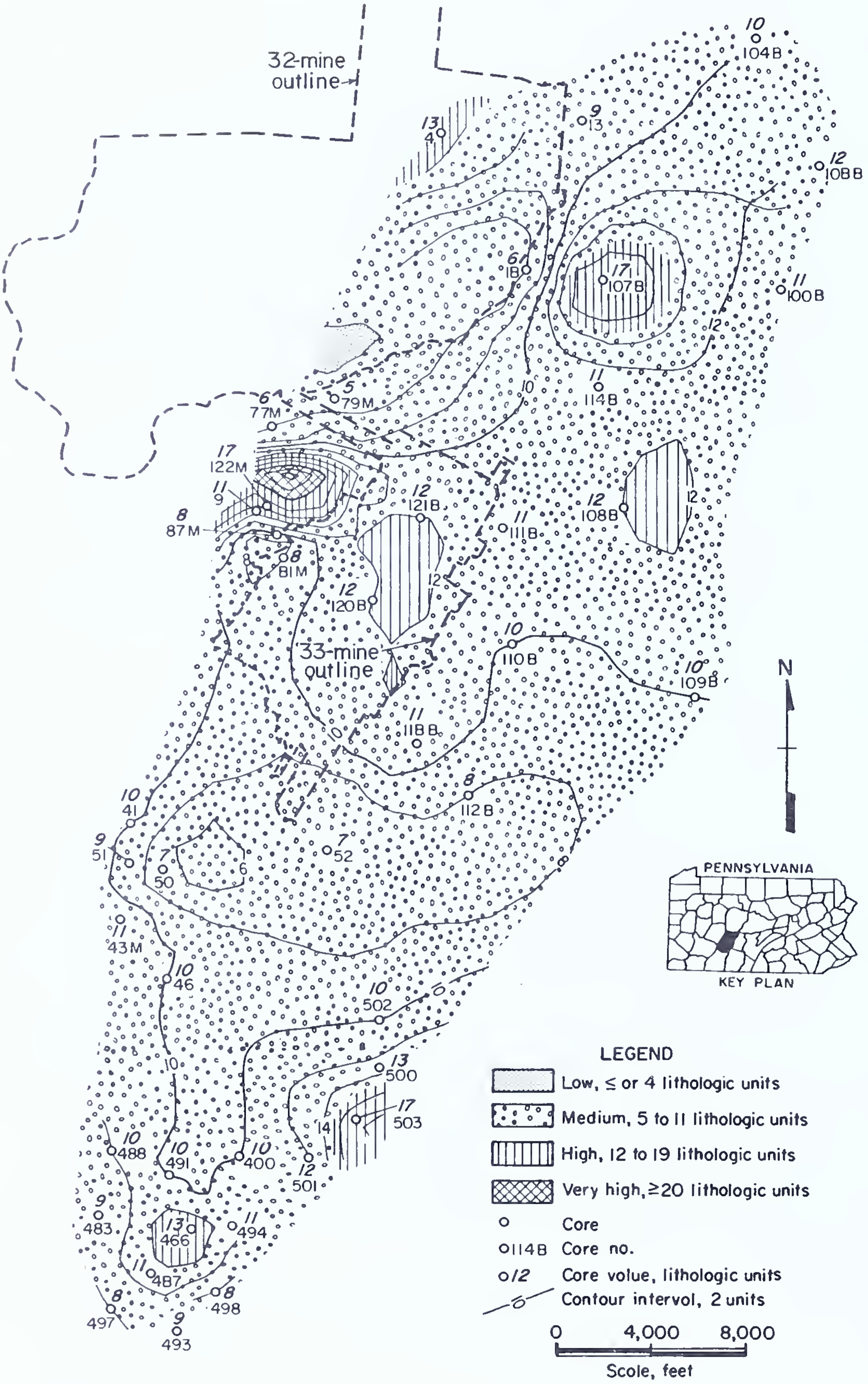


FIGURE 8. - Lithologic frequency map of interval between Lower and Upper Kittanning coalbeds.

not present a problem: Other factors that contribute to roof instability are a small vertical distance to the next higher coal and close joint spacing. A large distance to the next coal and wide joint spacing would greatly increase the probability of stable roof. Figure 9 is similar to the other lithologic frequency map (fig. 8) except that a variable coal-to-coal interval is involved. The interval now is from 20 to 55 feet, depending on where the next coal above the Lower Kittanning coal appears. There is a marked similarity between these two maps, especially in the northwestern part where there is rapid transition from less than five lithologic units to more than nine lithologic units in a horizontal distance of 2,000 feet. The interval between the Lower Kittanning and the next higher coal (whether the Middle Kittanning or a wild coal) was selected because, as was stated earlier, it was observed underground that the upper extent of most roof falls was the bottom of the coal directly above the Lower Kittanning coalbed.

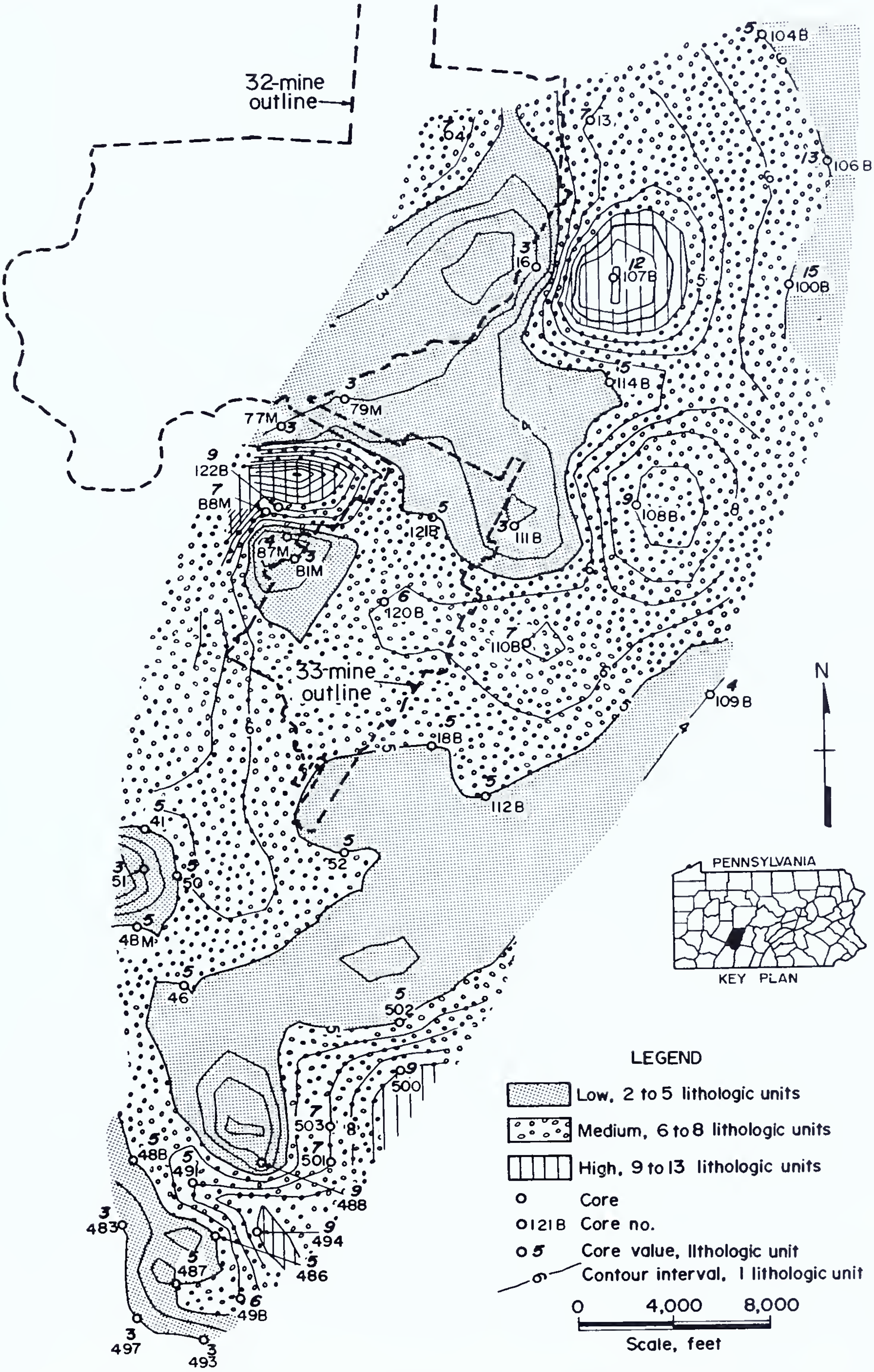


FIGURE 9. - Lithologic frequency map of interval between Lower Kittanning coalbed and next higher coalbed.

Relative Distribution of Sandstone and Shale

The maps showing the percentage of sandstone and the percentage of shale (figs. 10-11) outline a channel. In preparing these maps, the interval used was the 50 feet immediately above the Lower Kittanning coalbed. These maps show a high percentage of sandstone and a low percentage of shale, which define the channel area. Outside the channel there are, conversely, high shale and low sandstone percentages.

Shale Plus Limestone to Sandstone Ratio

Study of figure 12 substantiates the existence of a channel. A relatively large ratio number indicates a small percentage of sandstone in relation to shale and limestone. The small ratio numbers, representing sandstone-rich zones, can be followed through the middle of the map, indicating channel and sheetlike sandstone deposits. At the southern end, no definite sandstone pattern can be detected. The trend of the channel as inferred from this study is shown in figure 13. This shows that the inferred boundary between the channel sandstone deposit and shale follows the trend of known roof instability in the mines.

Vertical Thickness of Interval Between Lower Kittanning Coal and the Next Higher Coal

The interval between the Lower Kittanning coal and the next higher coal is critical because the uppermost plane along which the roof tends to separate is the bottom of the coalbed immediately above (whether a wild coal or the Middle Kittanning coalbed). From falls observed underground and related to this map (fig. 14) we find a correlation between roof instability and a thin zone, less than 30 feet (vertically) between the upper coal and the Lower Kittanning coalbed, especially where the roof strata are well jointed. Where this interval is more than 50 feet, the probability of roof instability is greatly decreased. The areas of highest occurrence of roof falls correlate with the thin areas of this interval on the isopach map and the areas of high frequency of lithologic units.

DISCUSSION AND ENGINEERING APPLICATIONS

On June 23, 1972, after the main theme of this report had been developed, a plan view of the two mines was received from the Bethlehem Mines Corp. showing areas of unstable roof. This map (fig. 15) was then reduced in size to overlay it on the panel diagram (or fence diagram) and the other maps used in this study. By comparing the map of unstable roof areas with the maps drawn by us, it became apparent that falls most commonly occur along the roof-margins of the channel fill sandstones which parallel the eastern boundary of both the Cambria 32 and 33 present mine workings. From these data we compiled a map (fig. 6) that shows where unstable roof is likely to occur in the future.

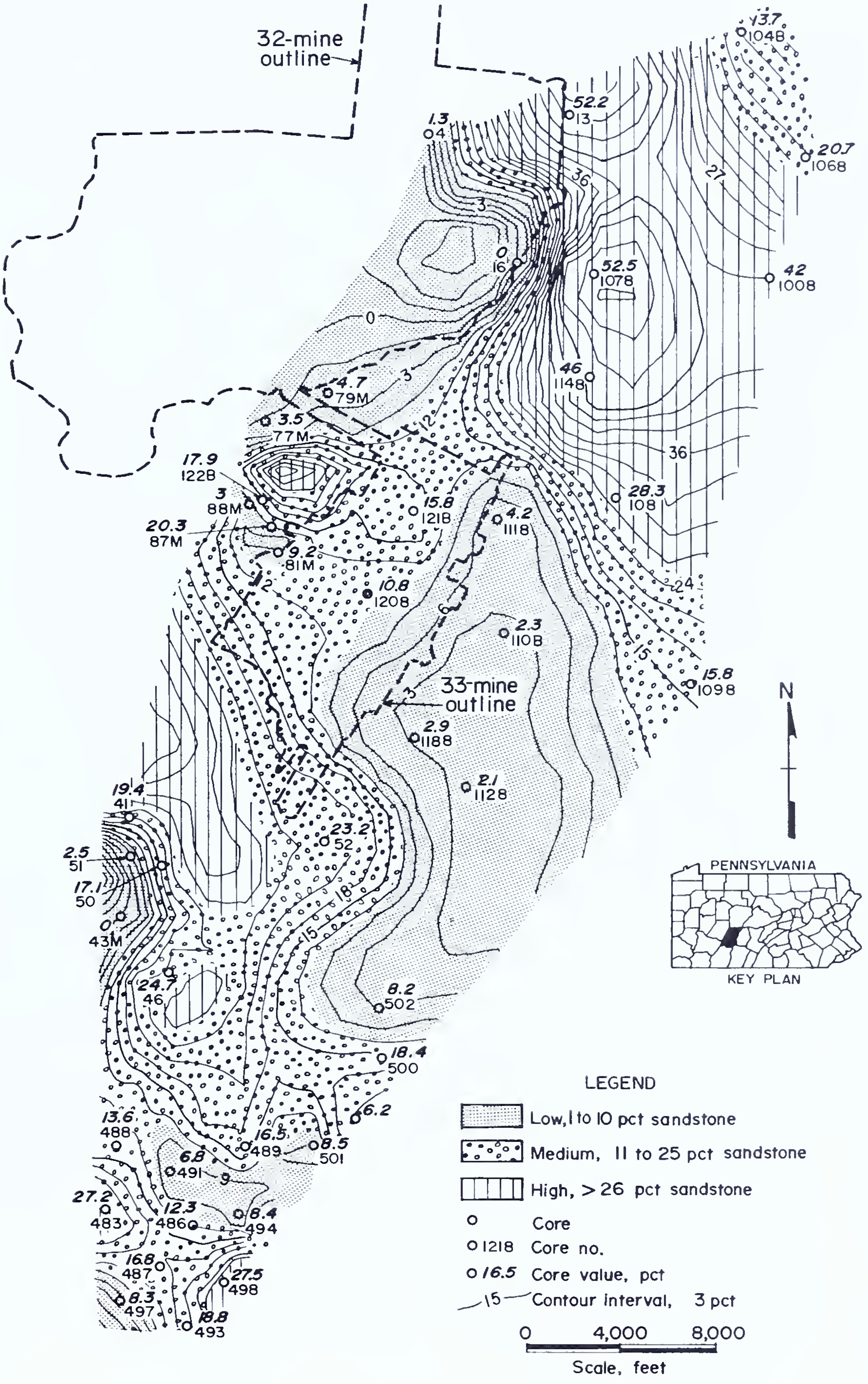


FIGURE 10. - Percentage of sandstone 50 feet immediately above the Lower Kittanning coalbed.

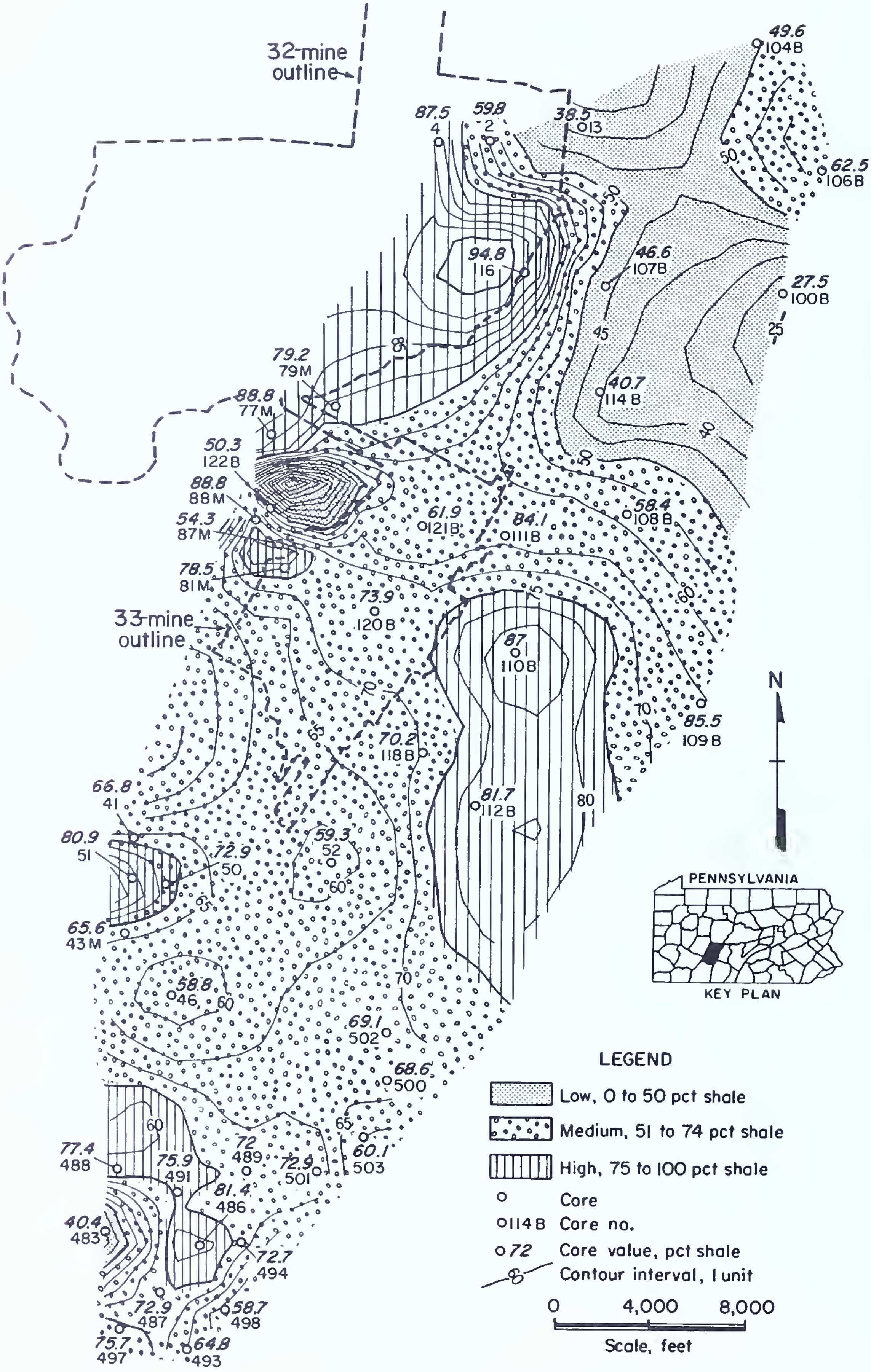


FIGURE 11. - Percentage of shale 50 feet immediately above the Lower Kittanning coalbed.

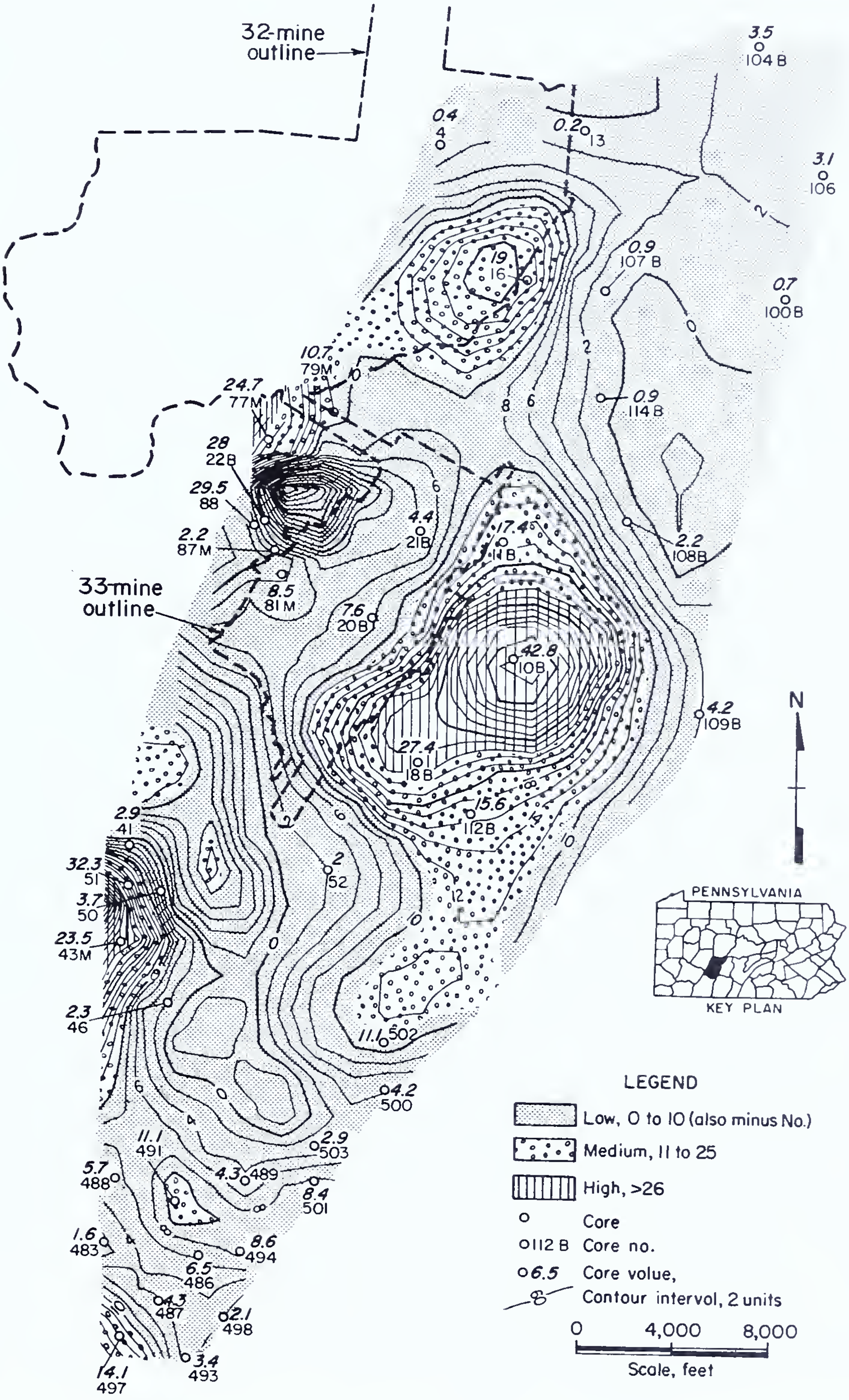


FIGURE 12. - Map of shale plus limestone to sandstone ratio.

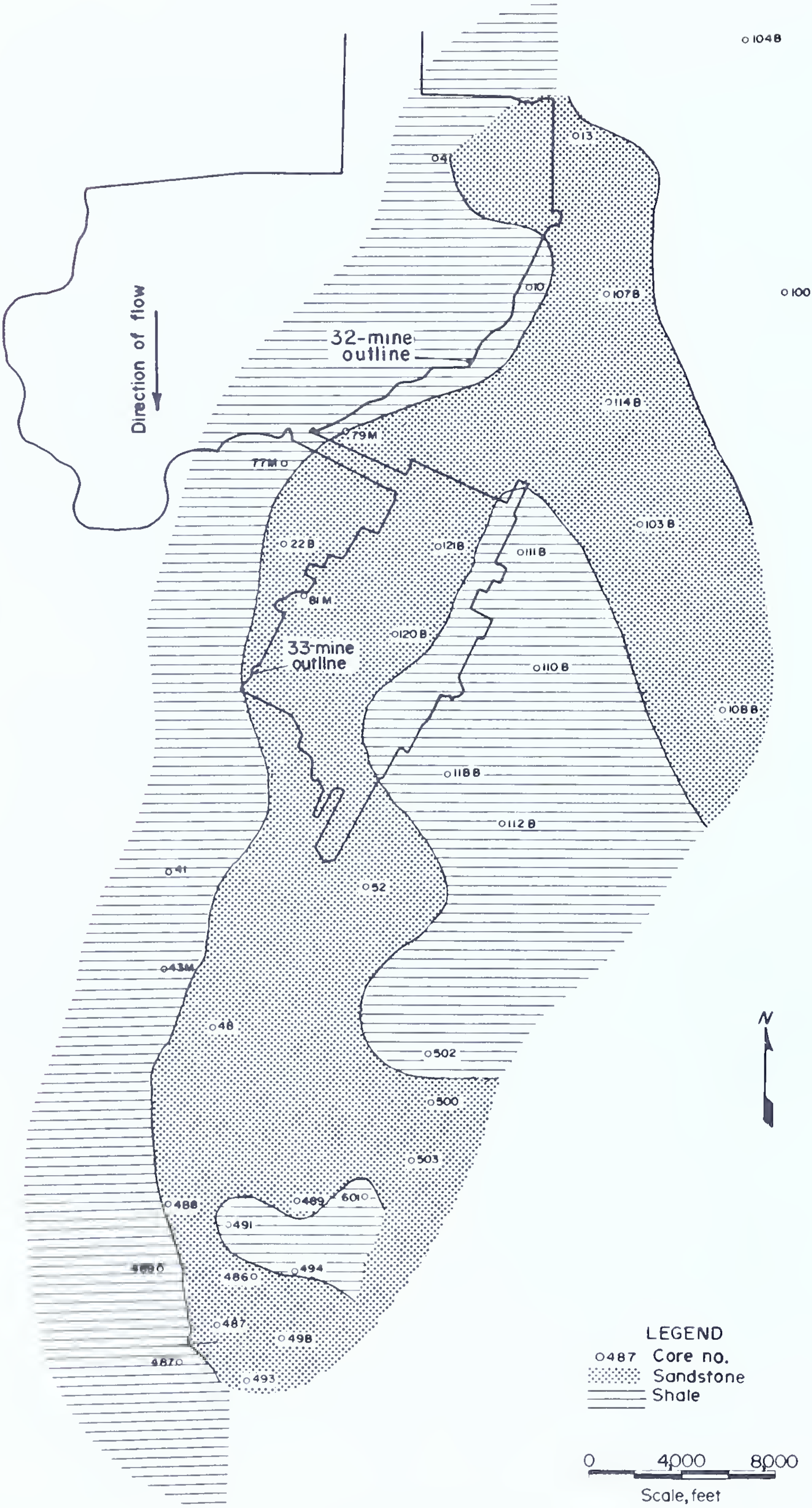


FIGURE 13. - Inferred sandstone-filled channel.

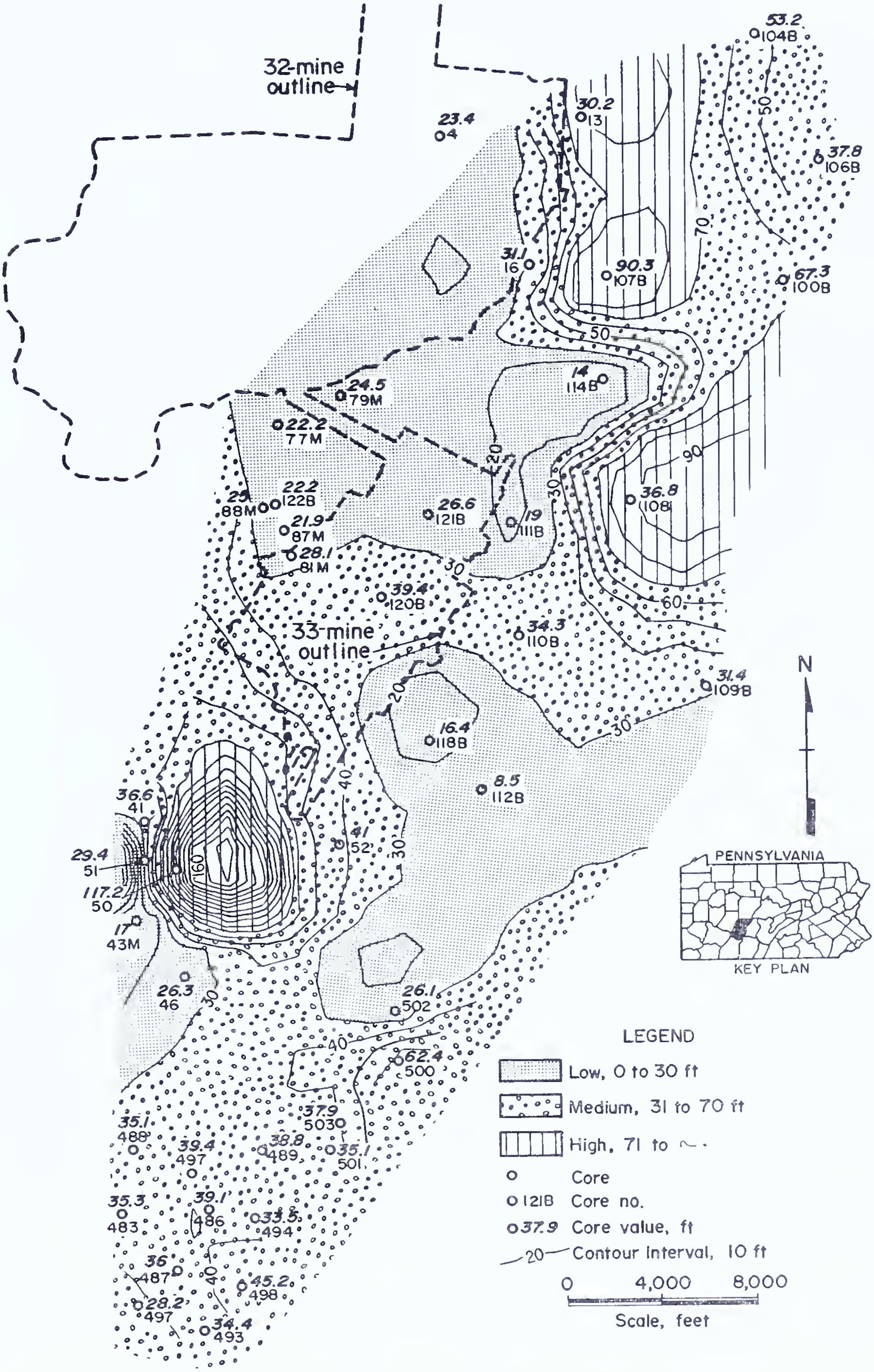


FIGURE 14. - Isopach map of interval between Lower Kittanning coalbed and next higher coalbed.

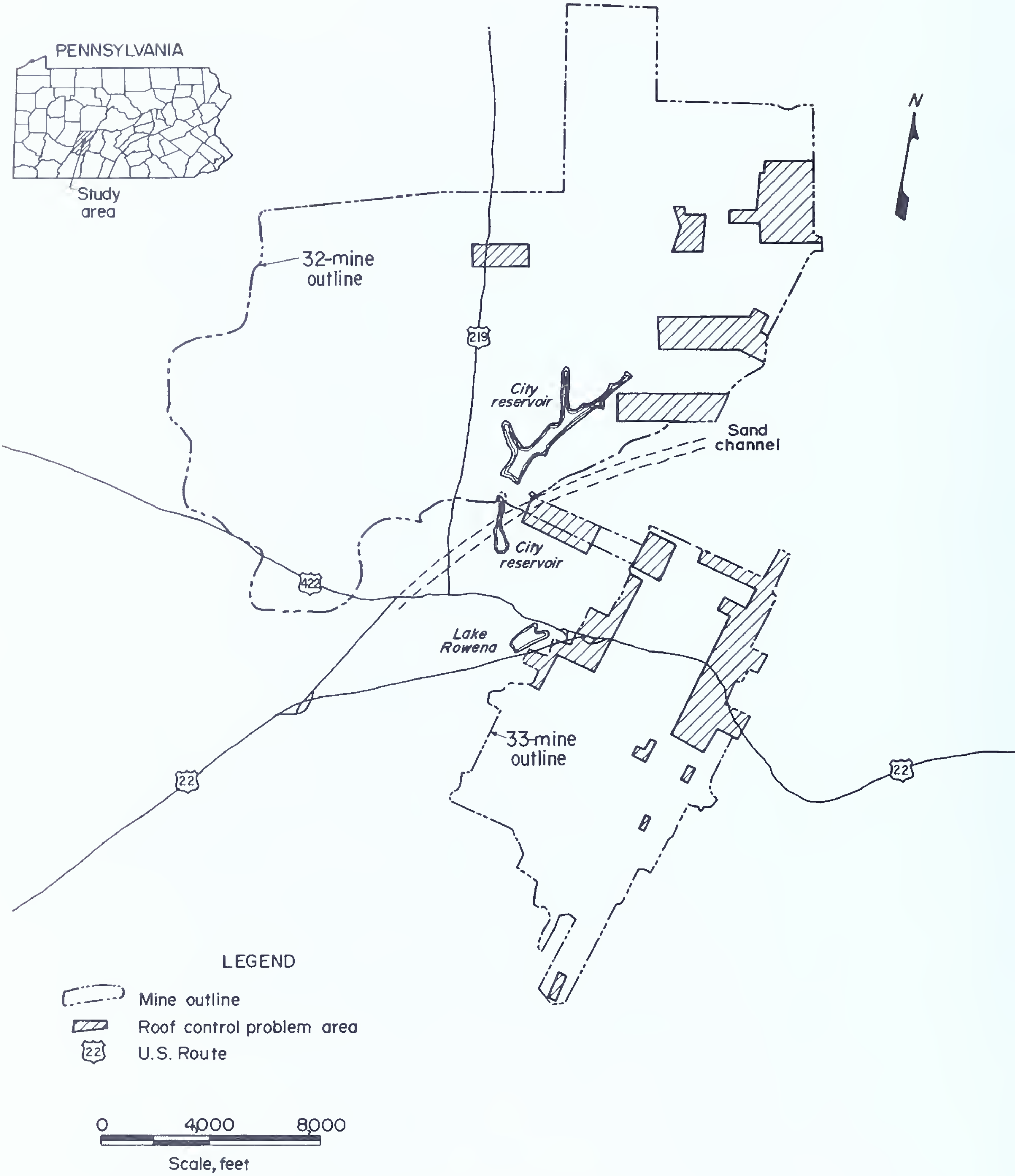


FIGURE 15. - Present mine working outline showing known areas of unstable roof.

CONCLUSIONS AND RECOMMENDATIONS

This study shows that methane emission in these mines is more closely related to roof falls and emission from strata above the Lower Kittanning coalbed than to any other single factor.

A channel sandstone deposit occurs immediately above the Lower Kittanning coalbed along the eastern part of the present No. 32 workings and extends over much of the No. 33 mine (fig. 12); this sedimentational feature is the cause of some of the mining problems encountered.

There are four geologic reasons for inherent roof instability in these mines: (1) Differential compaction of the sediments along the boundaries of the channel sandstone deposit, (2) a large number (generally more than nine) of lithologic units in the 30-foot interval above the Lower Kittanning coalbed, (3) the occurrence of another coalbed about 30 feet above the Lower Kittanning coalbed, and (4) a spacing of less than 4 feet between the systematic joints in the rock immediately above the Lower Kittanning coalbed. Examinations of roof falls in the mine indicate that falls usually are due to at least two of these reasons and that the first two are the major causes.

There is an alinement between the N 70° W regional lineation, the strike of the face cleat of the coal and systematic joints of surface rocks, and at most of the roof joints observed underground.

Consideration of the criteria for roof instability as developed in this report should aid in the planning for further mine development so that unexpected roof falls can be minimized. Furthermore, when development must proceed in areas where there is a high probability of roof instability, the mine operator will be able to anticipate and prepare for the consequences so as to arrive at an alternate plan for mining this area and providing supplementary ventilation to cope with the expected influx of methane.

Valuable data for such interpretation can be acquired from core-drilled vertical holes where detailed geological information is systematically collected. We recommend that more core holes be drilled at a distance no greater than 3,000 feet from the nearest existing hole. This would be especially helpful in determining if the criteria for roof instability are evident to the east and southeast of the present workings of the Cambria No. 33 mine.

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Report of Investigations 8226r

Geology and Methane Content of the Upper Freeport Coalbed in Fayette County, Pa.

By Peter F. Steidl

March 3 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

This publication has been cataloged as follows:

Steidl, Peter F

Geology and methane content of the Upper Freeport coalbed in Fayette County, Pa. / by Peter F. Steidl. [Washington] : Bureau of Mines, 1977.

17 p. : ill., maps, diagrams ; 26 cm. (Report of investigations - Bureau of Mines ; 8226)

Bibliography: p. 15-16.

1. Coal - Geology - Pennsylvania - Fayette County. 2. Methane. 3. Mine gases. I. United States. Bureau of Mines. II. Title. III. Series: United States. Bureau of Mines. Report of investigations - Bureau of Mines ; 8226.

TN23.U7 no. 8226 622.06173

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GEOLOGY AND METHANE CONTENT OF THE UPPER FREEPORT COALBED IN FAYETTE COUNTY, PA.

by

Peter F. Steidl[1]

ABSTRACT

As part of the Bureau of Mines methane control program, the Upper Freeport coalbed was studied in Fayette County, Pa., where this coalbed lies about 650 feet below the Pittsburgh coalbed and contains the largest remaining reserves of any coalbed in the county. Coal and overburden isopachs, structure and joint pattern maps, and a fence diagram were prepared using data from gas and oil exploration logs and coal outcrops. These maps will aid in determining the need and/or feasibility of degasifying the Upper Freeport coalbed in the study area. Much of the coalbed in this area is under 600 to 1,400 feet of overburden. By correlation with data from the Pittsburgh coalbed, the gas content at depths of this order is estimated to be between 140 to 300 cf/ton of coal, for a total of 190 to 400 billion cubic feet of methane in this coalbed in Fayette County.

INTRODUCTION

The Upper Freeport coalbed has been mined in Fayette County since about 1840, with the most active mining occurring from about 1900 to about 1945. Strip mines continue to operate in this coalbed in the eastern part of the county, but there are no longer any active underground mines although much coal is still minable.

The free swelling index and agglutinating values of the Upper Freeport coal are within the normal range for coking coals. High ash and sulfur content of this coal and the difficulty in cleaning it to levels acceptable for coking will limit its use for metallurgical purposes (16).[2] Blending may be necessary since analyses indicate a sulfur content greater than 1.5 pct.

The present study was undertaken as part of the Bureau of Mines methane control program and provides data on methane content, cleat orientation, and other characteristics of this coalbed where much coal is still present. Over 370 data points, including gas and oil wells, coal exploration holes, and outcrop exposures were used in preparing the maps (fig. 1).

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[1] Geologist, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

[2] Underlined numbers in parentheses represent items in the list of references preceding the appendix.

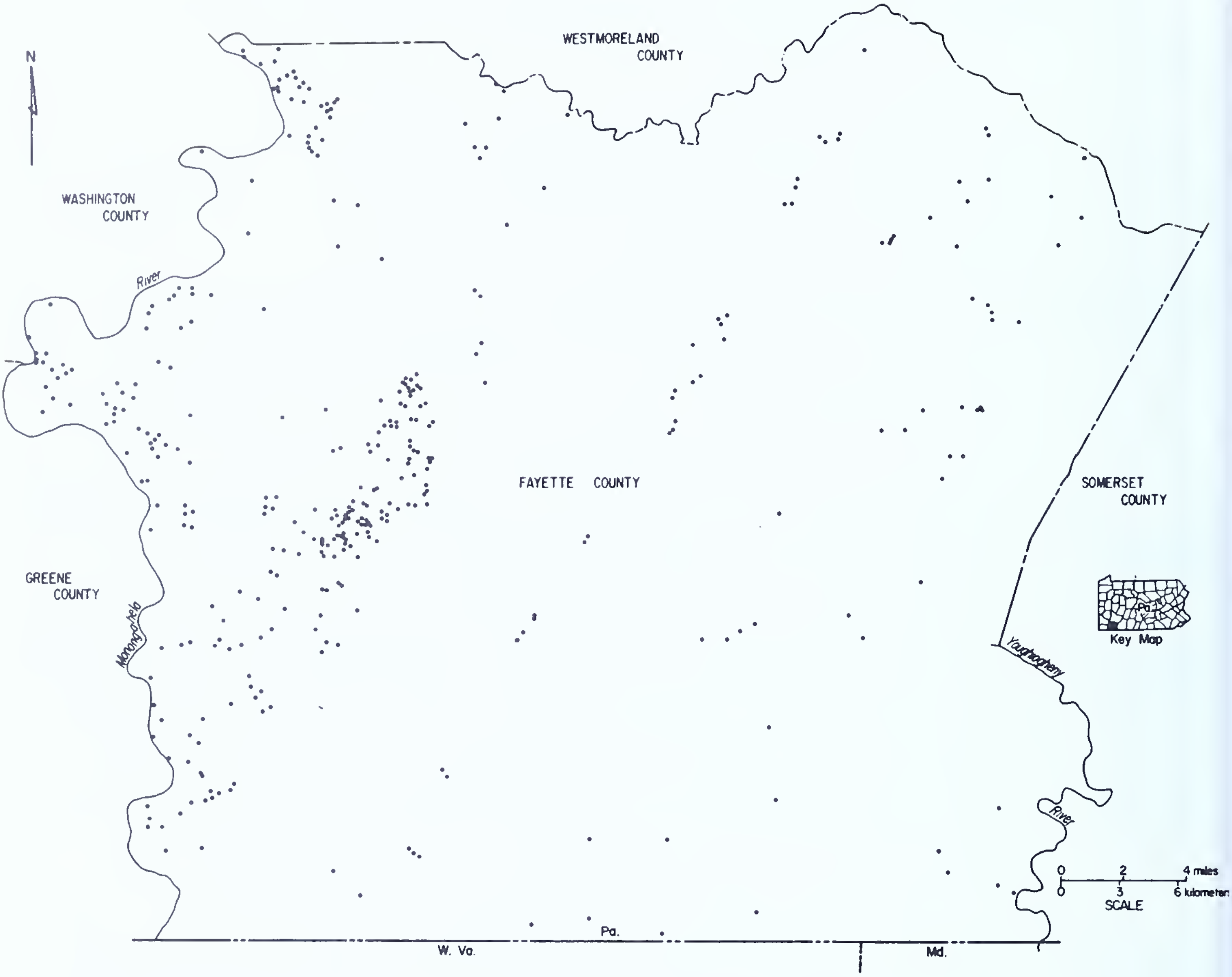

FIGURE 1. - Location of data points.

ACKNOWLEDGMENTS

The author thanks S. M. Linger, W. C. Doran, J. G. Tilton, and J. C. Patton of the Equitable Gas Co.; E. Campbell, P. Garrett, and T. K. Reeves of the Peoples Natural Gas Co.; R. H. Hoffman II, M. A. Sholes, and L. Heyman of the Pennsylvania Geological Survey; and S. E. Cortis and T. Alexander of the Pennsylvania Bureau of Subsurface Subsidence for supplying data. Thanks are also extended to H. E. Steinman of the Jones & Laughlin Steel Corp.; and W. E. Edmunds of the Pennsylvania Geological Survey for supplying data and reviewing the manuscript.

PREVIOUS WORK

There have been few previous investigations of the Upper Freeport coalbed in Fayette County. Past reports contain analyses and give carbonizing properties of the coal, as well as isopach and structure maps for parts of the county. Some coal thicknesses and outcrop descriptions from early reports provided useful data (1, 3-4, 13, 15). Hickok and Moyer (7) published a geologic map with coalbed outcrop lines for Fayette County in 1938. The structure map was drawn on the base of the Pittsburgh coalbed for the part of the county northwest of Chestnut Ridge and on the base of the Upper Freeport coalbed for the remainder of the county.

It has been estimated that the recoverable coal from this coalbed was 1,029 million tons in Fayette County in 1928 (12). This estimate was based on the assumption that the coalbed has a uniform thickness of 42 inches in townships along the Monongahela River. However, since its thickness is variable, a conservative 50 pct was used for the estimate of recoverable coal which does not include any part of the coalbed less than 18 inches thick. Subsequently this estimate was revised to 1,150 million tons (7). According to Dowd (5), the Upper Freeport coalbed contained the largest reserves of any coalbed in the county, but Dowd's estimate, which does not include inferred coal, was much lower than Hickok's (7). Dowd's figure of 127 million tons was based on reserves in beds 28 inches or more thick and a 52.9 pct recovery.

Hickok and Moyer reported that the Upper Freeport coalbed is fairly persistent in Fayette County and is cut out in some places and replaced by sandstone. Their study found the coalbed to range from 2 to 9 feet thick, with persistent clay partings. Unusual thicknesses of up to 16 feet, including sizable partings, were also observed.

A study by Koppe (9) of the Upper Freeport in adjacent parts of Allegheny, Butler, Armstrong, and Westmoreland Counties found basal partings in structurally low areas. He reports that "ancient topographic highs (areas of no partings) occupy positions relative to present anticlines suggesting that the paleotopography was controlled by the same structures observable today."

STRATIGRAPHY

The Upper Freeport coalbed occurs at the top of the Allegheny Group, about 650 feet below the Pittsburgh coalbed. Seven relatively thin and often discontinuous coalbeds (fig. 2) which may occur in 200 feet of stratigraphic section in the Allegheny and Conemaugh Groups make correlation difficult. One of the most useful aids in correlating these coalbeds is their depth below the Pittsburgh coalbed. Another aid in correlation is the Freeport limestone which sometimes occurs beneath the Upper Freeport coalbed underclay. The Mahoning (Dunkard) sandstone is usually present above as shown in the fence diagram (fig. 3). Two coalbeds occur within 55 feet of the Upper Freeport coalbed, the Mahoning coalbed above and the Lower Freeport below, neither of which is usually as thick or persistent as the Upper Freeport.

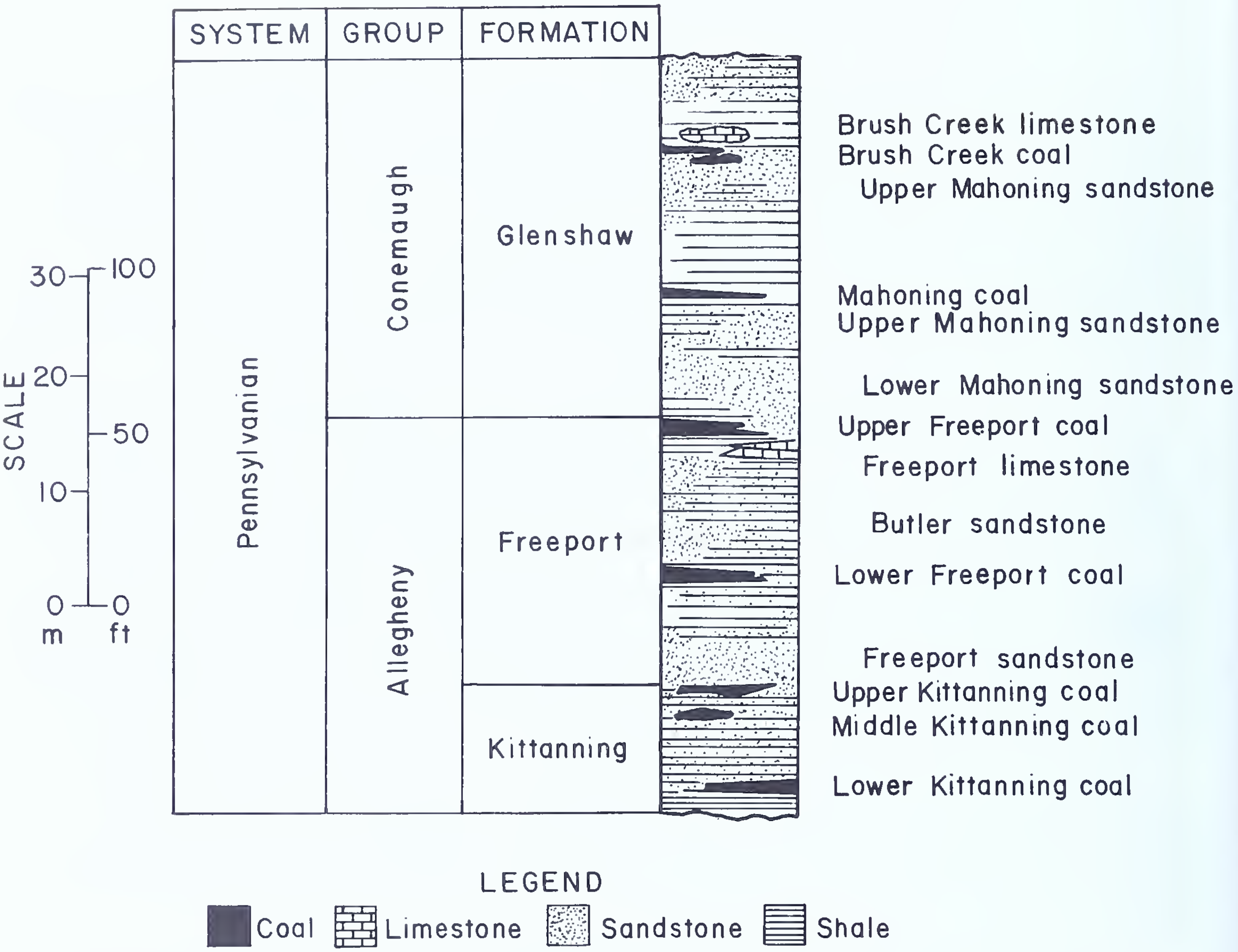

FIGURE 2. - Generalized stratigraphic column of the Upper Freeport coalbed and adjacent strata.

Due to the presence of an irregular surface beneath the Upper Freeport coalbed, there are areas where the peat was eroded or was not deposited. Evidence of this can be found along Chestnut Ridge where the lower Mahoning (Big Dunkard) sandstone cuts out some or all of the Upper Freeport coalbed (7). On some higher areas, plant remains were washed away to low areas or decayed before peat formed and therefore no coal is present.

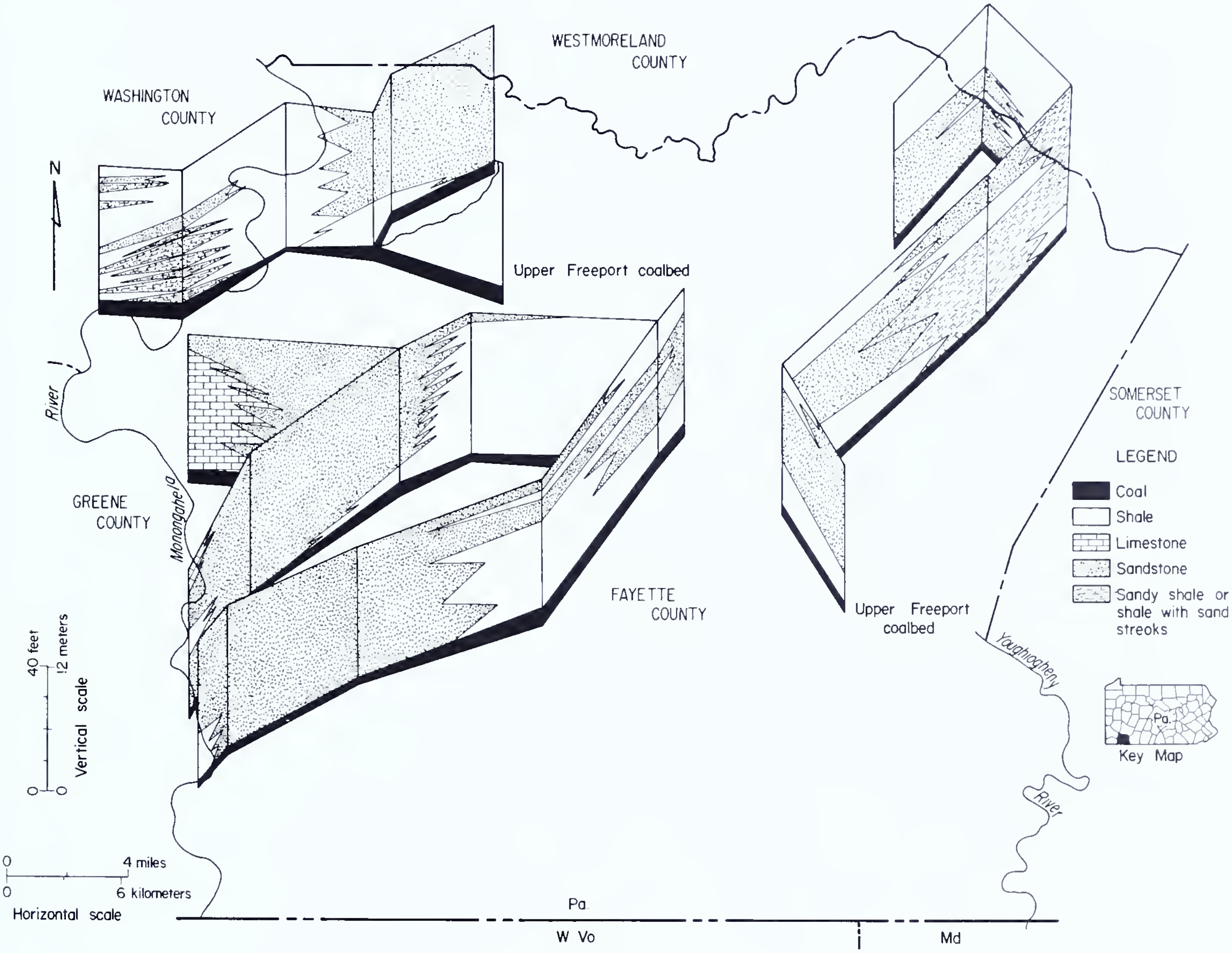

FIGURE 3. - Fence diagram of the 50 feet of strata above the Upper Freeport coalbed.

STRUCTURE

A structure map was drawn using the bottom of the Upper Freeport for the datum base (fig. 4).[3] Much of the structure was taken from a previous map (7) drawn on the base of the Pittsburgh coalbed for the part of the county northwest of Chestnut Ridge and on the base of the Upper Freeport coalbed for the remainder of Fayette County. The approximate structure for the Upper Freeport was derived by subtracting 650 feet from the elevation of the Pittsburgh coalbed. Other changes were made wherever additional data showed the need for them.

The major structures present from east to west are Laurel Hill anticline, Ligonier syncline, Chestnut Ridge anticline, Uniontown syncline, Fayette anticline, Lambert syncline, Brownsville anticline, and Port Royal syncline. All these structures trend northeast-southwest and affect the

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[3] The coal isopach, overburden isopach, and structure map are available from the author at scales of 1:24000 (1 inch equals 2,000 feet) and 1:96000.

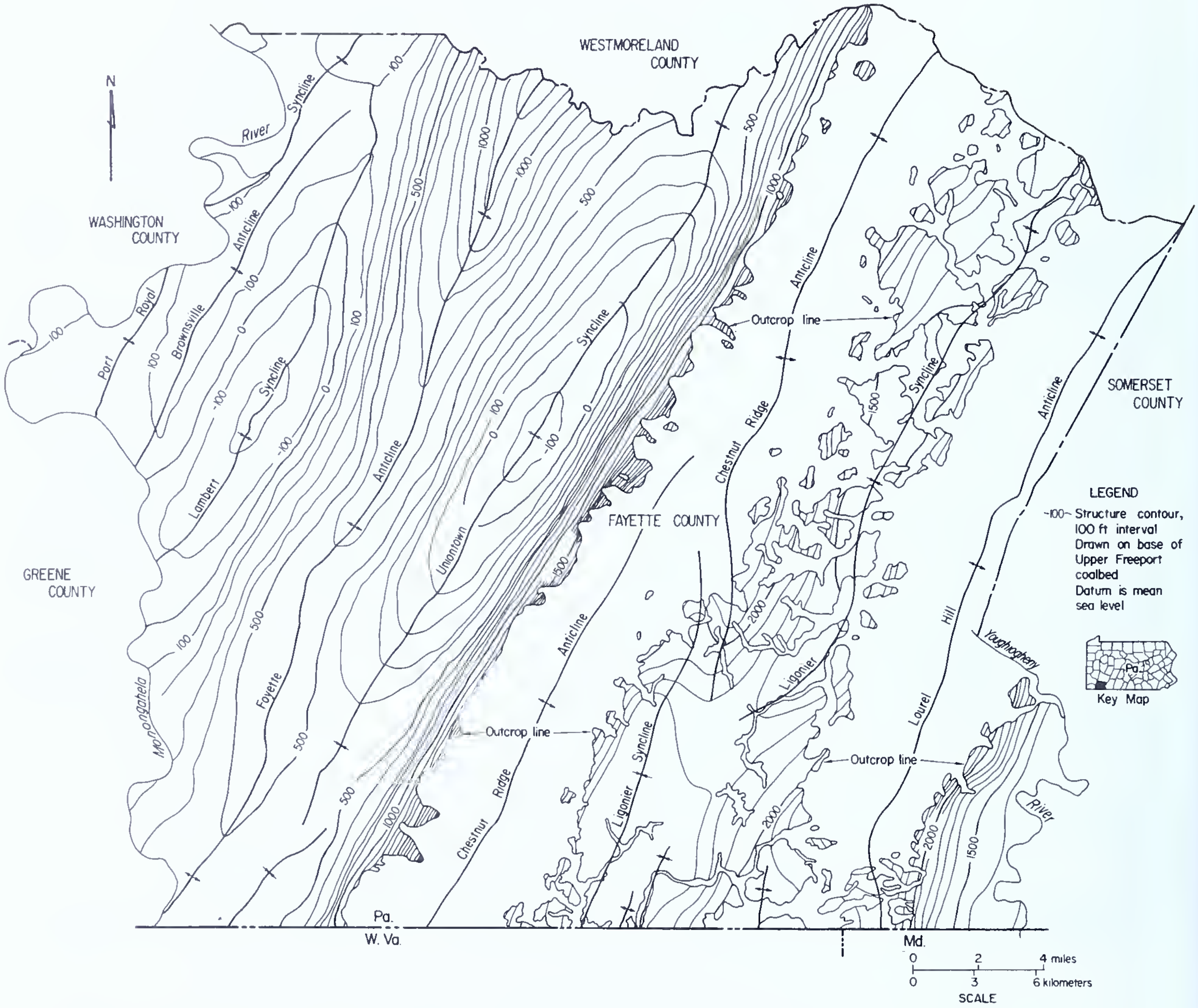

FIGURE 4. - Structure map drawn on the base of the Upper Freeport coalbed with structure northwest of Chestnut Ridge anticline projected down from structure for the Pittsburgh coalbed.

elevation and presence of coalbeds in the area. On Chestnut Ridge and Laurel Hill anticlines there are places where the Upper Freeport coalbed outcrops and large areas where it has been eroded.

Structural relief of the Upper Freeport coalbed in the study area is over 2,800 feet; the highest part (more than 2,600 feet above sea level) is located along the eastern flank of the Chestnut Ridge anticline, and the lowest part (more than 200 feet below sea level) is located in the Lambert syncline. There is moderate dip throughout most of the area with the beds varying from flat lying to dipping 23° (a slope about 2,200 feet per mile) on the western flank of the Chestnut Ridge anticline.

No faults are shown on maps of the study area. However, locations of three have been noted in the literature, two on the western side of Chestnut Ridge. One of the faults lies along the Western Maryland Railroad, south of South Connellsville, another is exposed along U.S. Route 40 near the Lick Hollow Picnic Area. The third fault is near the Monongahela River on the north side of Middle Run, north of Gates, Pa. Seismic study of the Summit gasfield has shown the presence of some subsurface faults (7).

OVERBURDEN

Overburden thickness for the Upper Freeport varies considerably within Fayette County. Overburden is thickest in the west where it is more than 1,400 feet. In the eastern part of the county the coalbed has been eroded from large areas on the Chestnut Ridge and Laurel Hill anticlines (fig. 5). In the Ligonier syncline which lies between these two anticlines, the overburden is usually less than 400 feet thick.

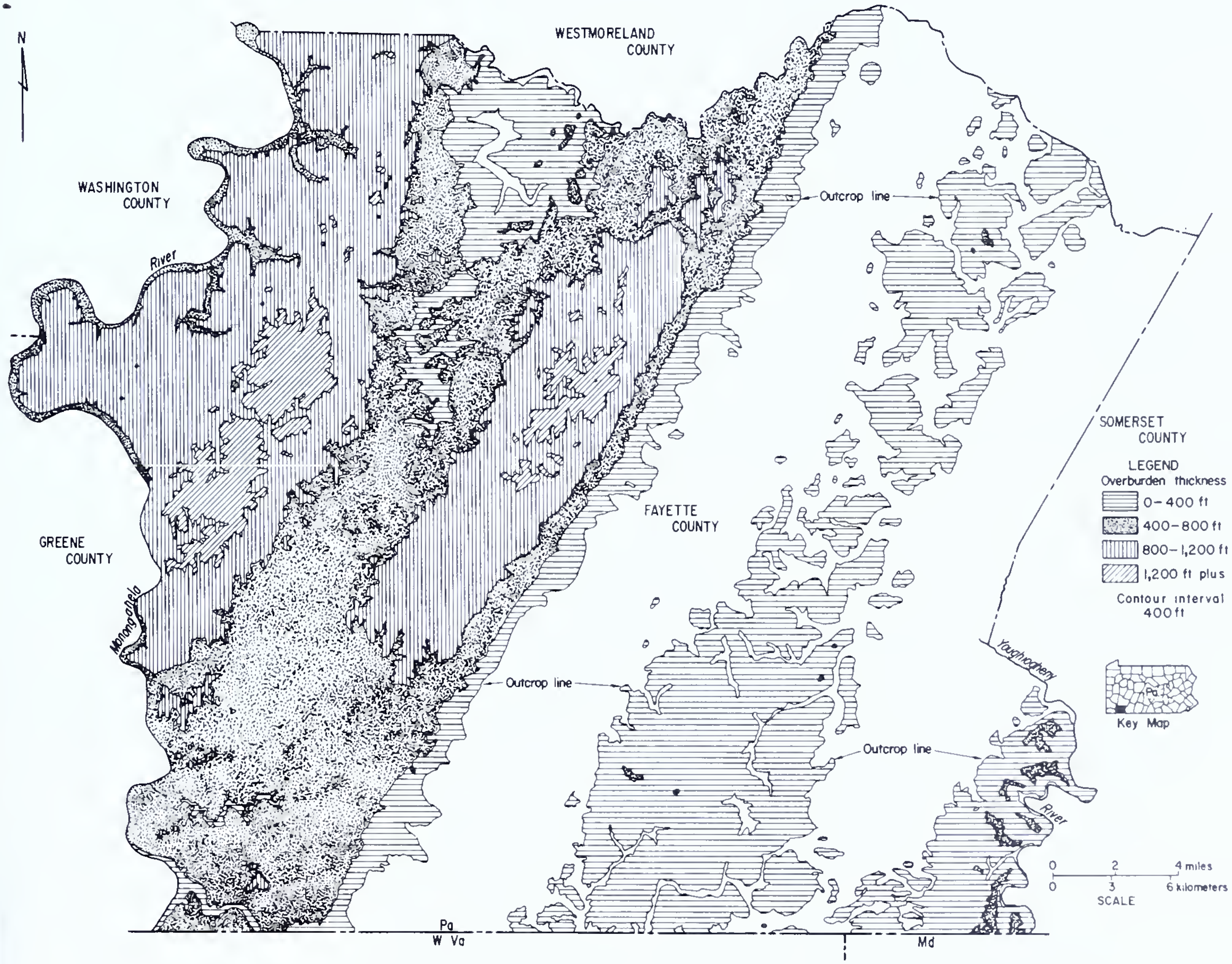

FIGURE 5. - Isopach of overburden thickness above the Upper Freeport coalbed.

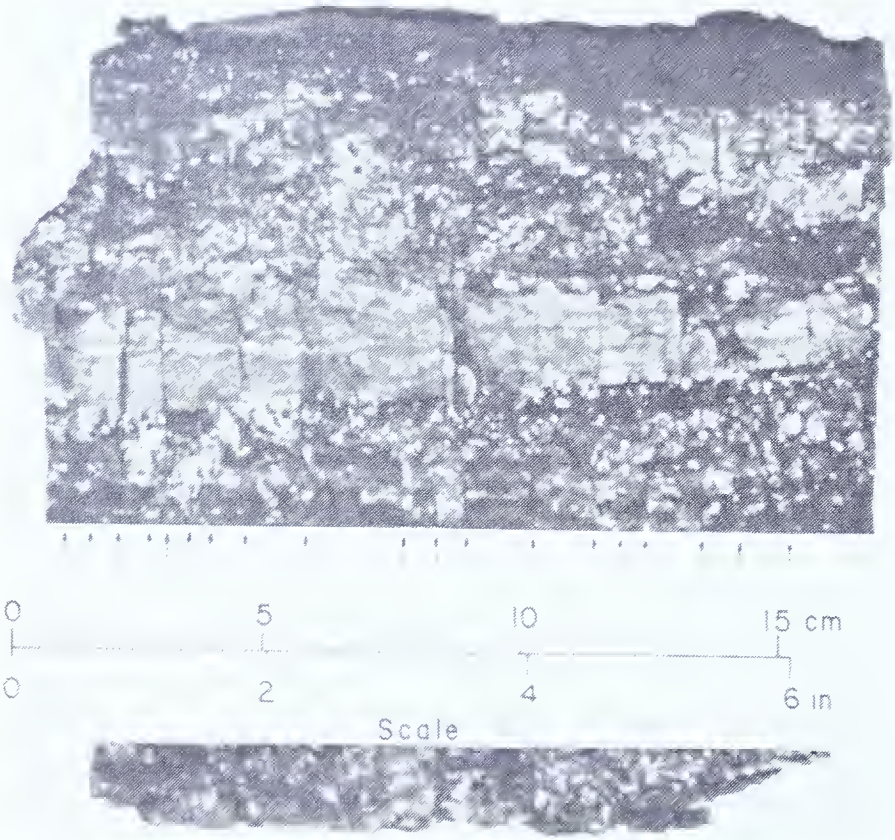

FIGURE 6. - Cleat spacing in specimen of Upper Freeport coal.

Many strip and drift mines have operated in the Upper Freeport on the flanks of the anticlines, where the coalbed outcrops or is close to the surface. In the northwestern part of the county, this coalbed has also been strip mined along its outcrop on the Youghiogheny River and Jacobs Creek.

JOINT AND CLEAT DATA

The Upper Freeport coal is friable and has a close cleat spacing (fig. 6) of around 40 face cleats per foot. Orientation of rock joints and coal cleats was measured from outcrops throughout the county to provide data for mine planning. These data can be important in laying out the mine, spacing vertical boreholes, and orienting horizontal holes drilled underground. Data were collected from 23 quadrangles and plotted on rose diagrams (fig. 7). For 8 of the quadrangles located totally or partially within the study area, an average of more than 16 locations were used, with an average of more than 8 measurements taken at each location. All but four quadrangles had locations where readings were taken from coalbeds.

In figure 8 distinct trends, corresponding to face and butt cleat directions, are apparent for readings taken in coal. The face cleat and systematic (primary) rock joints in the study area generally trend N 72° W. Nearly perpendicular to these are the butt cleat and the nonsystematic (secondary) joints which trend N 21° E. The face cleat direction is parallel to the direction of the principal compressive stress that produced the present structure and perpendicular to the fold axes. The butt cleat is parallel to the structural axes of the Allegheny Front.

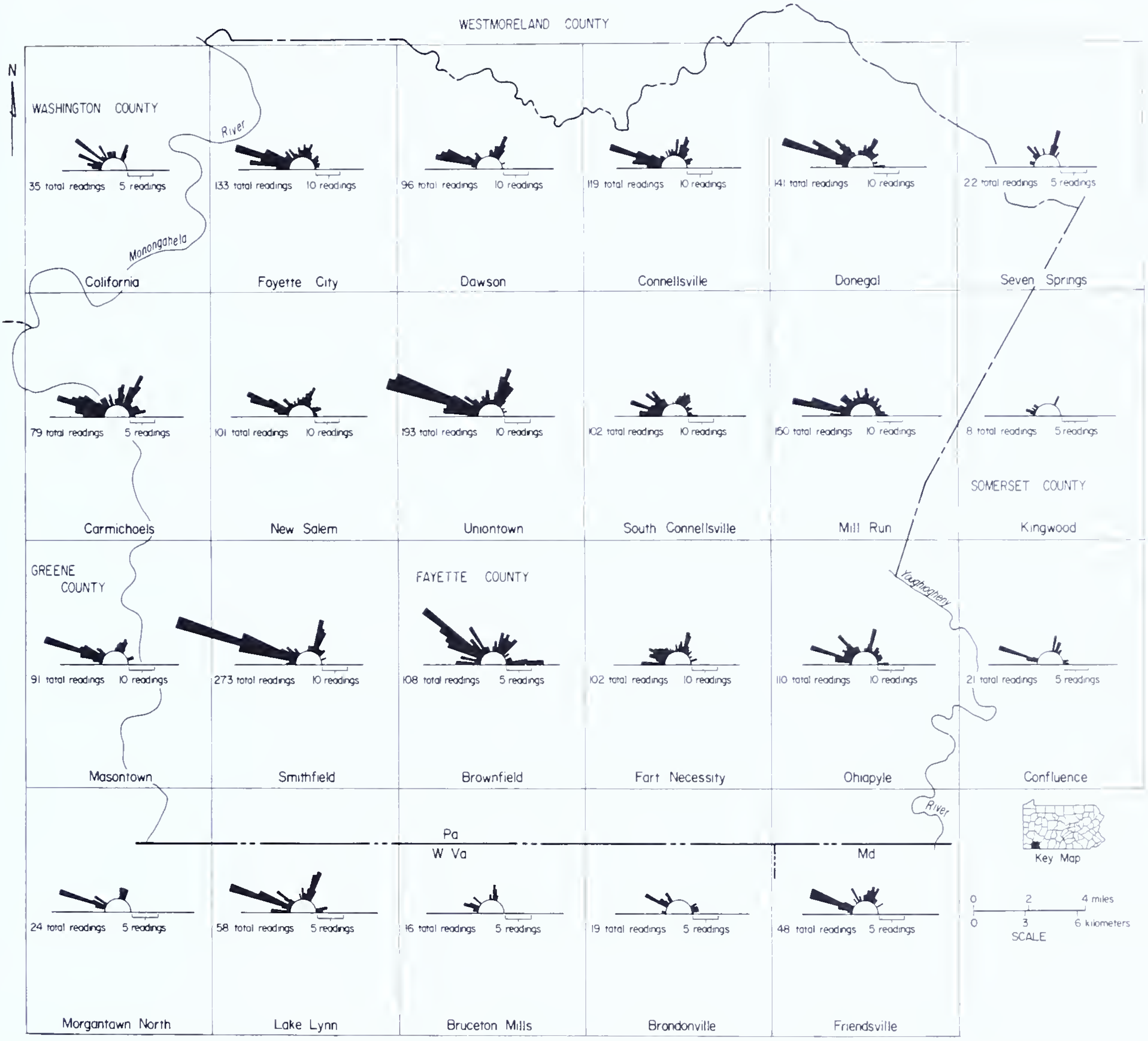
WESTMORELAND COUNTY
N
WASHINGTON COUNTY
River
Monongahela
35 total readings 5 readings
133 total readings 10 readings
96 total readings 10 readings
119 total readings 10 readings
141 total readings 10 readings
22 total readings 5 readings
California
Fayette City
Dawson
Connellsville
Donegal
Seven Springs
79 total readings 5 readings
101 total readings 10 readings
193 total readings 10 readings
102 total readings 10 readings
150 total readings 10 readings
8 total readings 5 readings
SOMERSET COUNTY
Carmichaels
New Salem
Uniontown
South Connellsville
Mill Run
Kingwood
GREENE COUNTY
FAYETTE COUNTY
Youghiogheny
91 total readings 10 readings
273 total readings 10 readings
108 total readings 5 readings
102 total readings 10 readings
110 total readings 10 readings
21 total readings 5 readings
Masontown
Smithfield
Brownfield
Fort Necessity
Ohiopyle
Confluence
River
Pa
W Va
Md
Key Map
24 total readings 5 readings
58 total readings 5 readings
16 total readings 5 readings
19 total readings 5 readings
48 total readings 5 readings
0 2 4 miles
0 3 6 kilometers
SCALE
Morgantown North
Lake Lynn
Bruceton Mills
Brandonville
Friendsville

FIGURE 7. - Rose diagrams of coal cleat and rock joint measurements in Fayette County, Pa.

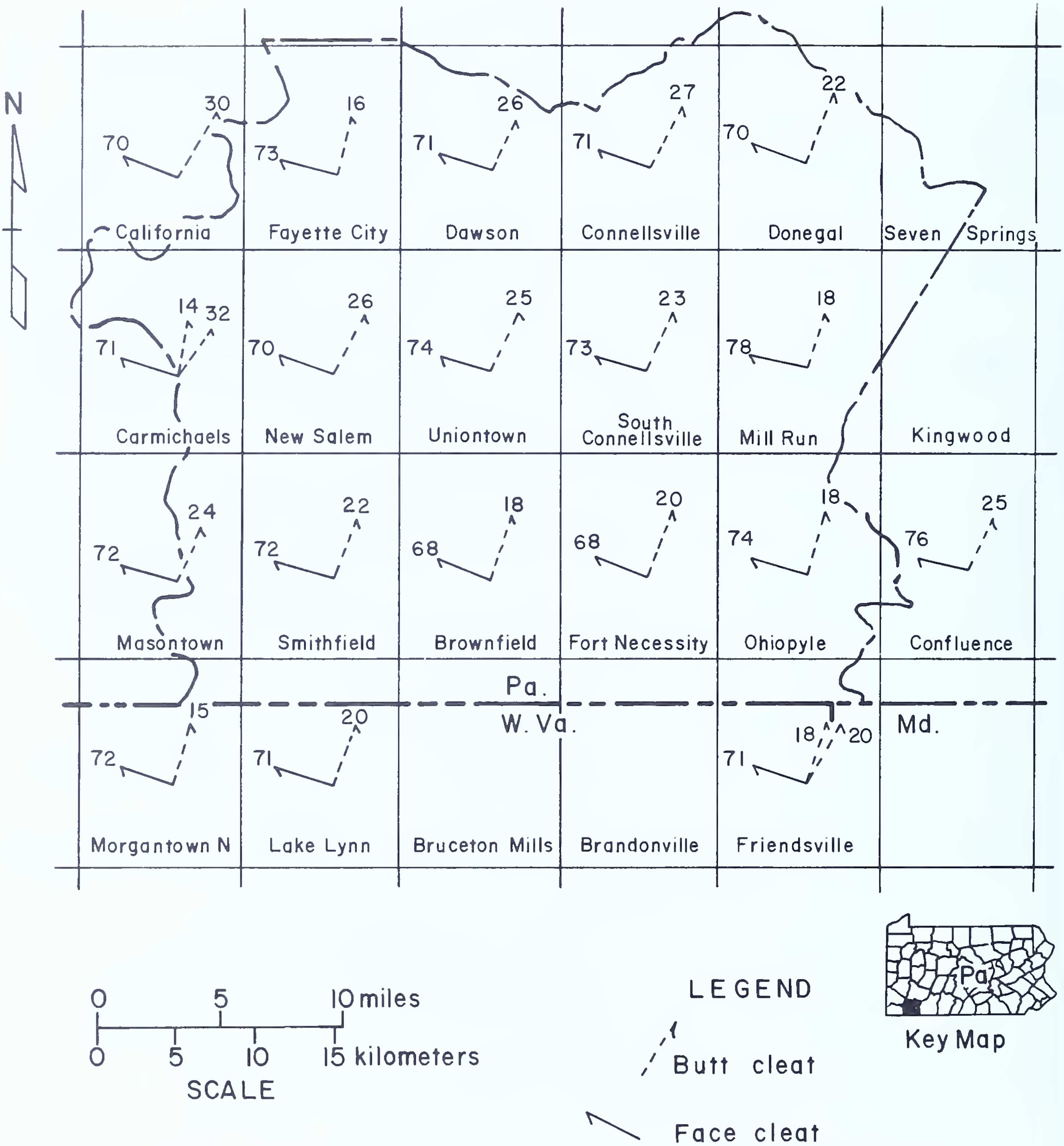

FIGURE 8. - Diagram of the face and butt cleat trends in each quadrangle.

COAL THICKNESS AND METHANE RESOURCES

Where present, the Upper Freeport coalbed usually ranges from 2 to 8 feet thick. Commonly the coalbed occurs in two benches with a 6-inch parting. The top and bottom benches average 25 and 21 inches thick, respectively. The shale parting rarely attains a thickness greater than 2 feet, but where it does only

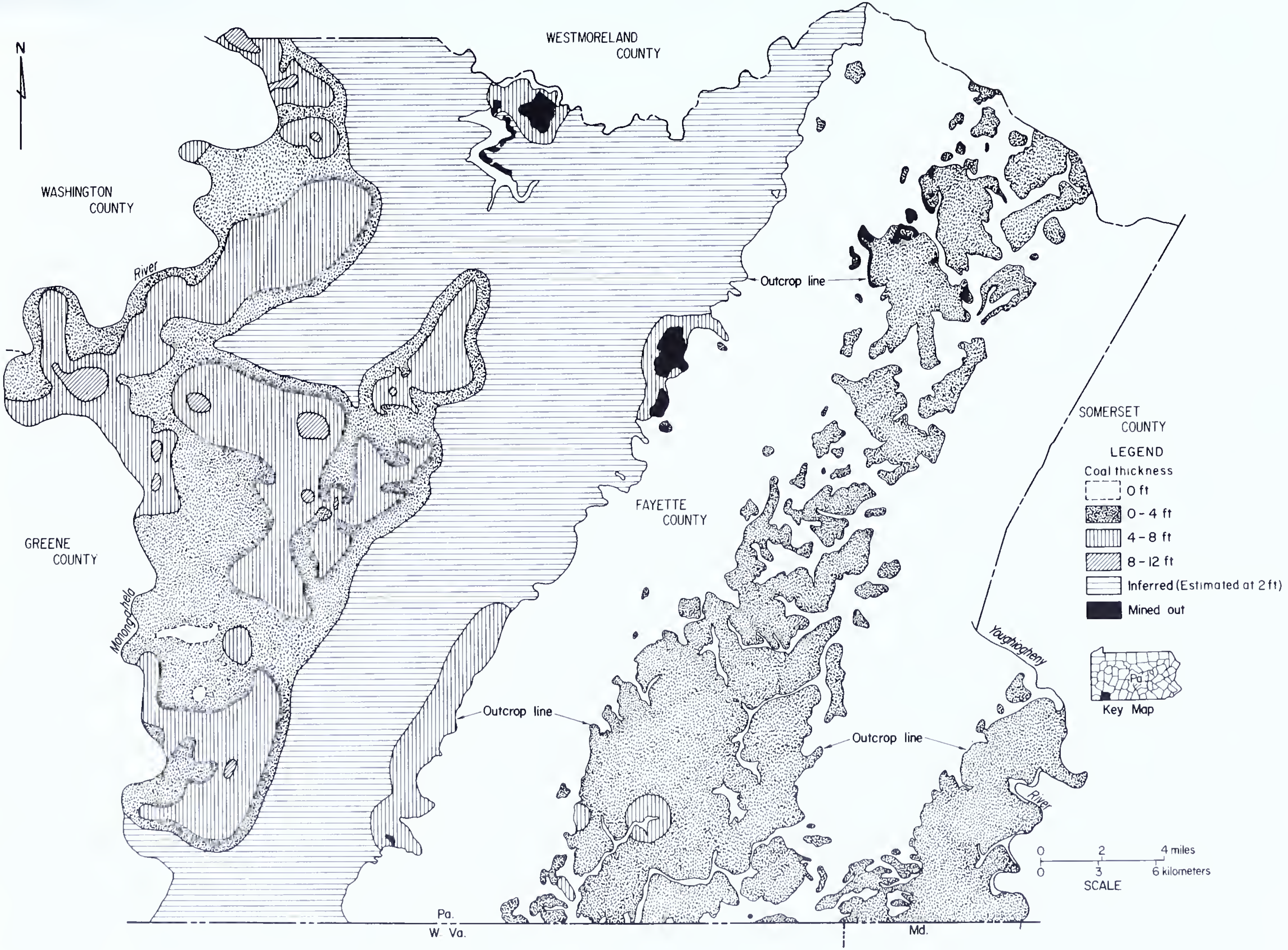

FIGURE 9. - Isopach of the Upper Freeport coalbed.

one bench is usually of minable thickness. Occasionally, there is a middle bench up to 3 feet thick or an upper split of the seam averaging 30 inches.

In order to calculate the total volume of methane in this part of the Upper Freeport coalbed, it was necessary to estimate the total coal in place. The area of each interval was measured from topographic maps. Multiplying this figure times the average coal thickness for the interval (2 feet for the 0- to 4-foot interval and so on) gives the volume of coal. Dividing the volume in cubic feet by 24.6 gives the number of short tons, assuming the specific gravity of this coal to be 1.3 (81.3 lb/cu ft). An equation for this follows:

$$\text{Tons of coal} = \frac{\text{average interval thickness} \times \text{interval area}}{24.6 \text{ cu ft/ton}}.$$

An estimate of 1,340 million tons of coal in place was made by using over 370 data points. In some areas there are insufficient data to draw isopach lines (fig. 9). There are, however, sufficient data points surrounding the area to assume an average thickness of 2 feet or more. Due to the highly variable thickness of the Upper Freeport coalbed in the study area, a conservative thickness of 2 feet was used to estimate the coal in place in these areas. Assuming methane content to be 140 to 300 cubic feet per ton of coal, there is 190 to 400 billion cubic feet of methane in the Upper Freeport coalbed in Fayette County.

METHANE CONTENT

The amount of methane adsorbed on the coal microstructure depends on several factors: temperature, pressure, overburden thickness, and rank. Coalbed pressure is the fluid pressure of the bed. At most it is equal to the hydrostatic pressure, which has a gradient of about 0.43 psi per foot of water column. Bureau research has shown that for each additional 100 feet of overburden, an increase of about 0.8 cu cm of methane per gram of coal (25.6 cu ft/ton) can be expected in the Pittsburgh coalbed (fig. 10). This correlates well with tests done on the Upper Freeport coalbed which has a gas content per volume of coal similar to the Pittsburgh coalbed.

In some coalbeds, the increase in gas content with the increase in depth is due partly to the decrease in volatile matter. However, pressure and temperature associated with past tectonic activity have had a much greater effect on the coal rank in the study area than present overburden thickness. The increased yield of methane is associated with the decrease in hydrogen content, which begins in the bituminous coal range (14). Higher rank coals have a structure which can adsorb more of the methane produced during coalification.

The relationship of gas content to fixed carbon content is shown on figure 11 (11). In Fayette County the Upper Freeport coal, which varies between 63 and 75 pct fixed carbon in DAF (dry ash free) samples, is expected to have a gas content between 3 and 10 cu cm/g, with some variation due to depth. In the study area this coal averages 68.5 pct fixed carbon from

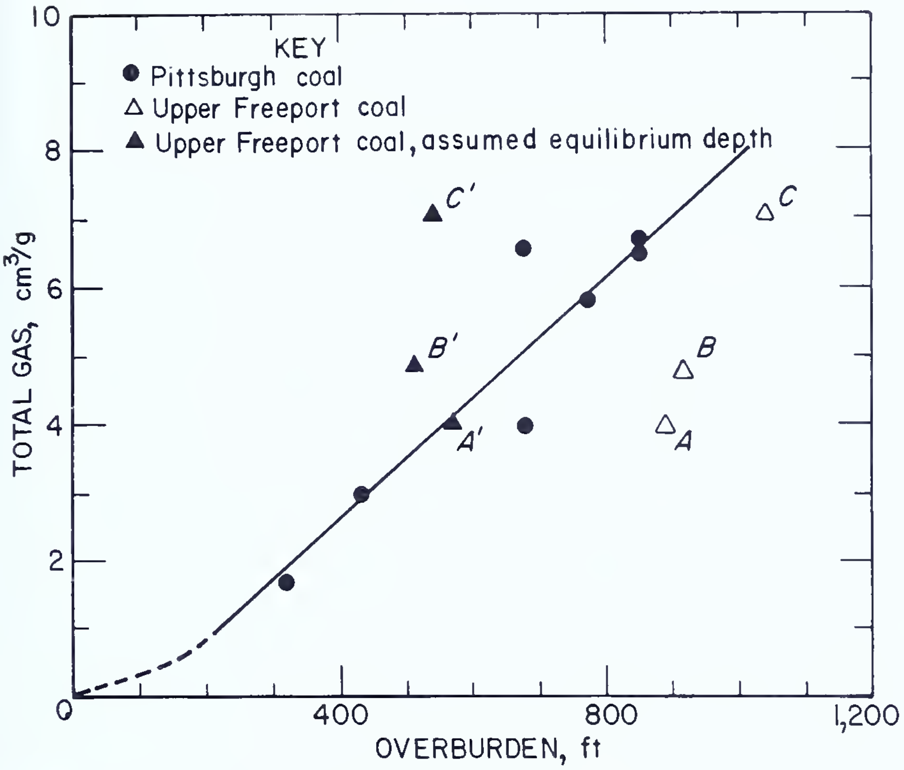

FIGURE 10. - Graph of depth versus gas content for Pittsburgh coal cores.

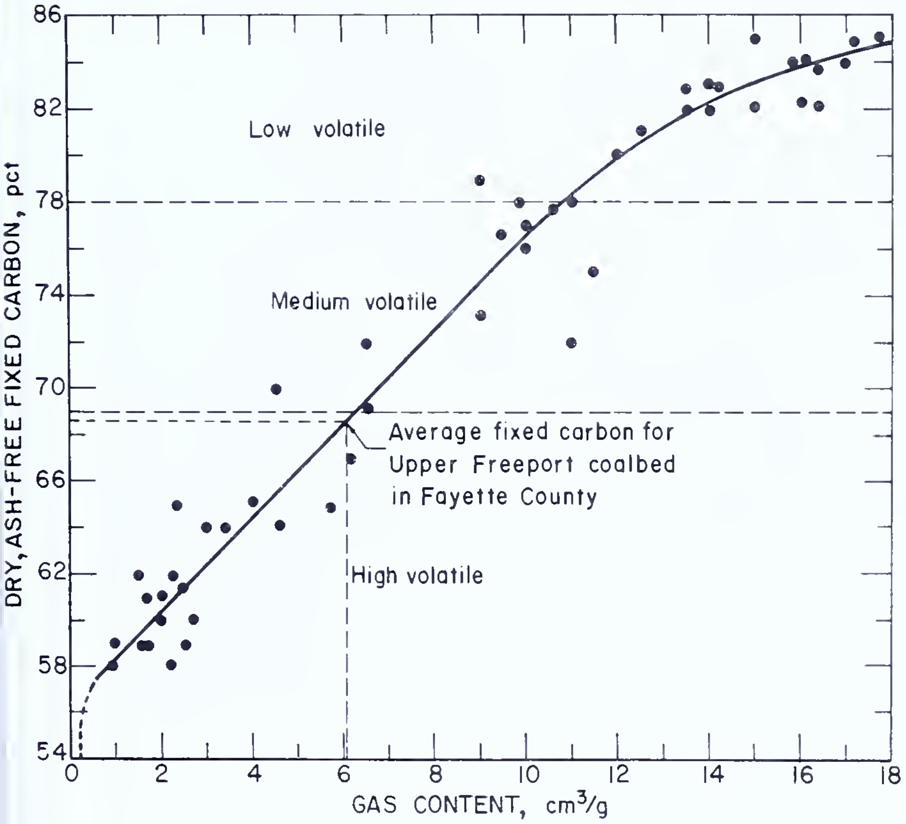

FIGURE 11. - Graph of fixed carbon versus gas content of coal cores from several coalbeds, adapted from previous publication (11).

published analyses (2, 6-7) and should average about 6.1 cu cm of methane/g of coal. This is only 13 pct higher than the value determined by the direct desorption method for three Greene County core samples (8, 10). Results from these tests are plotted on the graph of data from the Pittsburgh coalbed (fig. 10). The average depth of these three samples was 962 feet, and the average gas content was 5.3 cu cm/g. A reason for this anomaly could be a reduction in overburden pressure due to mining of the overlying Pittsburgh coalbed, thus establishing new equilibrium conditions. The lower hydrostatic pressures could cause gas to desorb from the Upper Freeport coalbed. New points have been plotted for the Upper Freeport coalbed by subtracting the overburden above the mined Pittsburgh coalbed to reflect the assumed equilibrium depths (A′, B′, and C′, fig. 10).

An important but unknown factor is the length of time necessary for gas to desorb from a coalbed under such conditions and a new equilibrium to be established. Points A′ and B′ plot closely to points on the graph for the Pittsburgh coalbed, however, point C′ does not. This point could be influenced by the overlying virgin Pittsburgh coalbed to the west and southwest, and point C may indeed be the true depth equilibrium for this core sample.

SUMMARY AND CONCLUSIONS

The Upper Freeport coalbed in Fayette County contains 190 to 400 billion cubic feet of methane based on an estimate of the total coal in place. The methane content is assumed to be 140 to 300 cubic feet per ton of coal. The total coal in place was determined by using 370 data points. The variable thickness of the coalbed in this area will require careful property evaluation and mine planning.

The structural elevation ranges from 200 feet below to 2,600 feet above sea level, and overburden thickness ranges from 0 to over 1,400 feet. The face cleat trends N 72° W, and the butt cleat trends N 21° E.

Degasification in advance of mining may be advisable for parts of the coalbed with more than 200 cu ft of methane per ton of coal in place. Gas contents of this order can be expected where the Upper Freeport is under more than 800 feet of overburden, mostly in the western part of the county. Due to the variable nature of the Upper Freeport coalbed in this area, a core hole spacing of 2,000 feet or less may be necessary to accurately determine reserves and low coal areas.

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APPENDIX.--AVERAGE OF COAL CLEAT TRENDS FOR INDIVIDUAL QUADRANGLES IN THE STUDY AREA

Quadrangle	Face cleat peak	Butt cleat peak
Brownfield	68 W	18 E
California	70 W	30 E
Carmichaels	71 W[1]	14 E, 32 E[2]
Confluence	76 W	25 E
Connellsville	71 W	27 E
Dawson	71 W	26 E
Donegal	70 W	22 E
Fayette City	73 W	16 E[2]
Fort Necessity	68 W	20 E
Friendsville	71 W	18 E, 28 E[2]
Lake Lynn	71 W	20 E
Masontown	72 W	24 E
Mill Run	78 W	18 E
Morgantown North	72 W	15 E[1]
New Salem	70 W	26 E
Ohiopyle	74 W	18 E
Smithfield	72 W	22 E
South Connellsville	73 W	23 E
Uniontown	74 W	25 E[1]

[1] Wide peak.
[2] Double peak.

Report of Investigations 8022

Geologic Investigations of Underground Coal Mining Problems

By C. M. McCulloch, P. W. Jeran, and C. D. Sullivan
Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.

March 3 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

Jack W. Carlson, Assistant Secretary—Energy and Minerals

BUREAU OF MINES
Thomas V. Falkie, Director

This publication has been cataloged as follows:

McCulloch, Charles M

Geologic investigations of underground coal mining problems, by C. M. McCulloch, P. W. Jeran, and C. D. Sullivan. [Washington] U.S. Bureau of Mines [1975]

30 p., illus. (U.S. Bureau of Mines. Report of investigations 8022)

Includes bibliography.

1. Coal mines and mining. I. Jeran, Paul W., jt. auth. II. Sullivan, C. D., jt. auth. III. U.S. Bureau of Mines. IV. Title. (Series)

TN23.U7 no. 8022 622.06173

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GEOLOGIC INVESTIGATIONS OF UNDERGROUND COAL MINING PROBLEMS

by

C. M. McCulloch,[1] P. W. Jeran,[1] and C. D. Sullivan[2]

ABSTRACT

A series of geological surveys were completed in six coal mines in connection with a Bureau of Mines research program on methane control. The aim of these surveys was twofold: First, to study the overall geology of the coalbed, and second to use the resulting data to evaluate the influence of the geological characteristics of the coalbed on safe and efficient coal extraction.

This report explains the advantages of geologic maps and fence diagrams in coal mining, and how the knowledge gained from such geologic investigations of mines can help control many underground problems.

INTRODUCTION

In connection with a Bureau of Mines research program on methane control in coal mines, a series of geological surveys were completed in six mines: Three in the Pittsburgh coalbed and one each in the Upper Freeport, Pocahontas No. 3, and Lower Hartshorne coalbeds. The aim of these surveys was twofold: First, to study the overall geology of the coalbed area and second to use the resulting data to evaluate the influence of the geological characteristics of the coalbed on safe and efficient coal extraction.

Such geological investigations can help to alleviate many underground mining problems (3).[3] They can locate sand channels that may intersect and cut out the coal in advance of mining. They can determine trends of channels, making it possible to predict their probable course and influence on future mining operations.

Clay veins can be located and their trends sometimes established. Thus, the high gas concentrations that frequently occur with clay veins can be anticipated.

---

[1] Geologist.

[2] Physical science aid.

[3] Underlined numbers in parentheses refer to items in the list of references preceding the glossary of terms.

A detailed map of the rock above the coalbed can be used to determine the length of bolts needed to support the roof and to locate competent strata into which the bolts can be anchored. Because certain rocks deteriorate rapidly when exposed to air, such a map can also help to determine areas where rock is of the type in which experimental resin bolts can be used.

An abnormal accumulation of water can be evaluated, and in many cases related to fracturing of the roof rock, or to a fault zone which can also be responsible for high gas concentrations.

A detailed joint pattern in the area of the mine can be established and examined for a possible relation with the coal cleat directions and with joints present in the roof. Local deviations in joint and cleat directions can serve as a basis for modifying mining conditions. The cleat and joints can also supply information on roof stability. Excessive spalling of ribs when mining with the cleat direction can sometimes be corrected by a 45° rotation of this direction.

ACKNOWLEDGMENTS

The authors wish to thank the staffs of Bethlehem Mines Corp., Island Creek Coal Co., Eastern Associated Coal Corp., Helvetia Coal Co., and Howe Coal Co., without whose assistance a report of this type could not have been prepared. These companies all supplied data for the preparation of maps and met with Bureau personnel to discuss the company mines. Bureau personnel worked underground in all mines and were escorted by company officials to any of the sections of the mine requested.

GEOLOGIC MINE SURVEY TECHNIQUES

Maps of Mine Problem Areas and Their Preparation

Maps of problem areas within mines are a necessary preliminary to an underground survey. Such maps are sometimes supplied by the company. They may show (1) zones of roof fall, (2) zones of excessive spalling of ribs, (3) zones of channel washouts, (4) zones of abnormal concentrations of clay veins, and (5) zones of excessive accumulations of water and gas. Very few maps show clay veins, sandstone channels, and so forth, but many companies do have maps of zones of bad roof or areas where a specific feature occurs with an abnormally high frequency.

When company maps were not available or were inadequate, Bureau personnel constructed their own maps. The majority of all maps were prepared from data taken from the corehole logs supplied by the company. The accuracy of the resulting data relates to the accuracy of the driller's log. Coreholes should be spaced at not more than 3,000 feet and when possible should be drilled on a suitable grid system. Interpretation of the driller's logs can be a problem, and it is helpful if the same driller has logged most of the holes, although when a number of holes have been drilled over a period of years, this may not be possible. Corehole logs can be used to prepare a variety of maps, including isopach maps of given intervals, structure maps, percent maps of rock units, lithologic frequency maps, lithofacies maps, and fence diagrams. The analysis of inherent problems is dependent upon such maps.

Underground Surveys

The geologists planning an underground survey first consult with company personnel as to the specific problems that may exist in the mine. Once underground, the geologic features of particular interest to the geologist himself are (1) orientation of coal cleats, (2) occurrence of clay veins, (3) occurrence of faults, (4) sandstone-or claystone-filled channels, (5) abnormally high concentrations of gas and water, and (6) roof falls.

Coal cleat measurements are used to determine the face and butt orientations of individual mines. The cumulative information is used for correlation with local and regional structure (4).

Clay veins or sedimentary dikes are a particular problem in mining because they may intersect so as to form isolated blocks of coal that may act as gas cells. When a continuous miner cuts through such a clay vein, the sudden rush of methane into the working area can greatly increase the fire and explosion hazard. Clay veins are also areas of mine roof instability. In the Pittsburgh coalbed, at sites where there are large numbers of clay veins, they appear to be controlled by structure, but additional evidence is needed to confirm this.

Where sandstone channels are encountered in mining, they must be penetrated by driving rock tunnels by drilling and blasting. This is a time-consuming operation that interrupts coal production. In particular, the plough-type longwall miner requires an area relatively free of sand channels and clay veins, while the shearer type may be able to mine through these areas without too much trouble.

Faults may displace a coalbed and also create areas of abnormally high gas and water accumulation. In many mines faults are hard to detect because they are of the strike-slip type, with no verticaloffset. Moreover, the cleat readings near a fault can differ greatly from the overall pattern of the area. A rotation of local cleat direction has been detected to 2,000 feet from the fault itself.

Surface Fieldwork

Generally a quick check is also made of the surface geologic features around the mine. Joints in the rocks are measured following guidelines of Lahee (2). Surface areas directly above underground problem areas are of special interest. When faults are encountered underground, the trend is plotted and its expression on the surface is sought.

Documentation

All available aerial photographs, IR photographs, SLAR mosaics, and photo index sheets of the area were examined for linears. The State geological

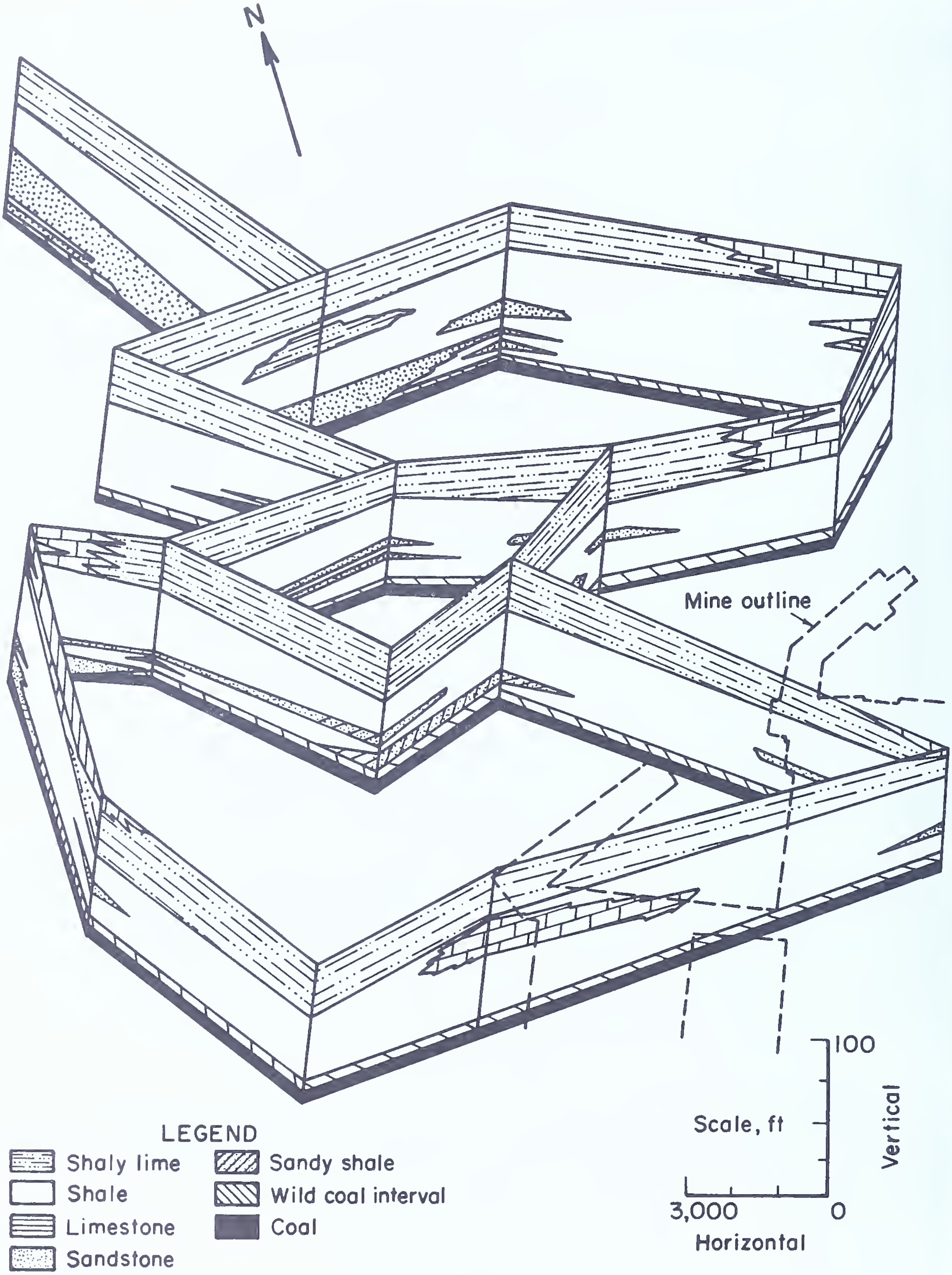

FIGURE 1. - Fence diagram of strata above the Pittsburgh coalbed, Marianna No. 58 mine.

surveys were contacted for any additional information on the study area, and the literature was checked for pertinent information.

SURVEYS OF SIX MINES AND THEIR PROBLEMS

Surveys were conducted in the following mines: Marianna No. 58 and Somerset No. 60, Bethlehem Mines Corp.; Lucerne No. 6, Helvetia Coal Mining Co.; Beatrice, Island Creek Coal Co.; Federal No. 2, Eastern Associated Coal Corp; and Howe, Howe Coal Co. Each mine presented different structural problems.

Marianna No. 58 Mine

The mine is located near Ten Mile, Pa. off Interstate Highway 79. It operates in the Pittsburgh coalbed. The survey, conducted in September 1972, showed the main directions of the cleat to be N68°W (face) and N28°E (butt). Mining is by the room-and-pillar method, and average methane emission per day is 2.3 MM ft^3. They are now mining at 45° to the cleat direction because of excessive spalling of the pillars and some roof control problems when mining parallel to the cleat directions. This change in direction has greatly reduced the amount of spalling and has caused no slowdown in mining.

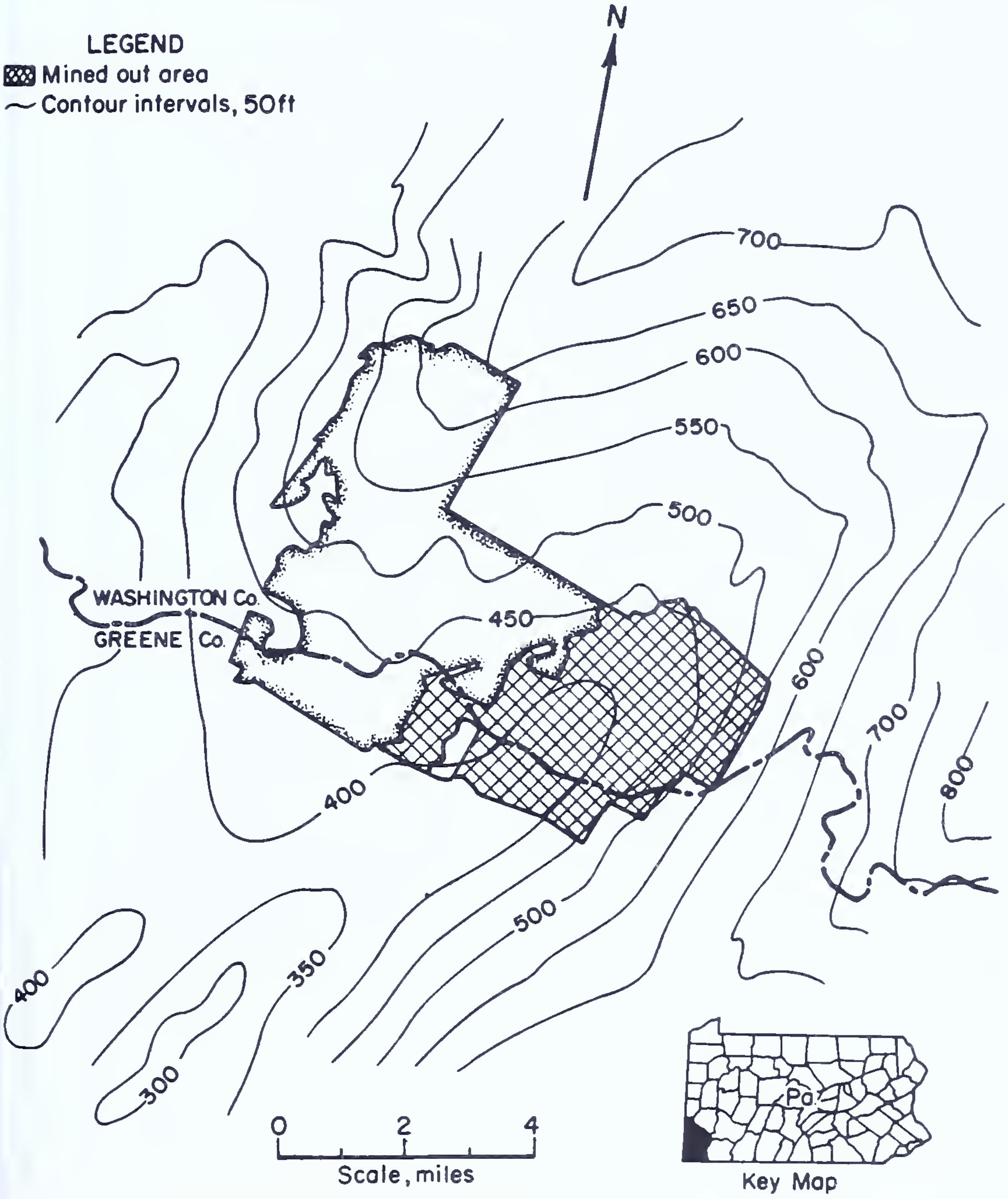

FIGURE 2. - Structure drawn on base of the Pittsburgh coalbed, Marianna No. 58 mine.

A panel (see glossary) or fence diagram (fig. 1) and a structure map (fig. 2) of the property were prepared. A topographic map was overlayed on the mine map to correlate the topography over the mine with problems encountered underground. A number of falls seem to aline with and occur under streams in the area. Because most streams form along zones of weakness, it was felt that this zone parallel to the stream would be a problem whenever it was encountered (fig. 3). Research currently underway further supports this idea. Another zone of falls associated with abnormally high gas emissions was found where the cover changed abruptly from 300 to 700 feet. This was attributed tentatively to differential overburden pressures.

The major problem throughout the mine was the wild coal interval formed by alternating thin bands of claystone and coal that overlay the coal. The interval ranged in thickness from 1 to 9 feet and could not support itself. The company was using roof bolts with a minimum length of 6 feet and a standard length of 7 feet; these were adequate where the wild coal was less than 6 feet thick. An isopach map of the wild coal interval (fig. 4) showed where this unit is greater than 6 feet thick; longer roof bolts would be needed in these areas.

A section affected by clay veins was carefully mapped. Comparison with a structure map of the area revealed the presence of a syncline with the clay veins located along its axis (fig. 5). As some of the mine entries had

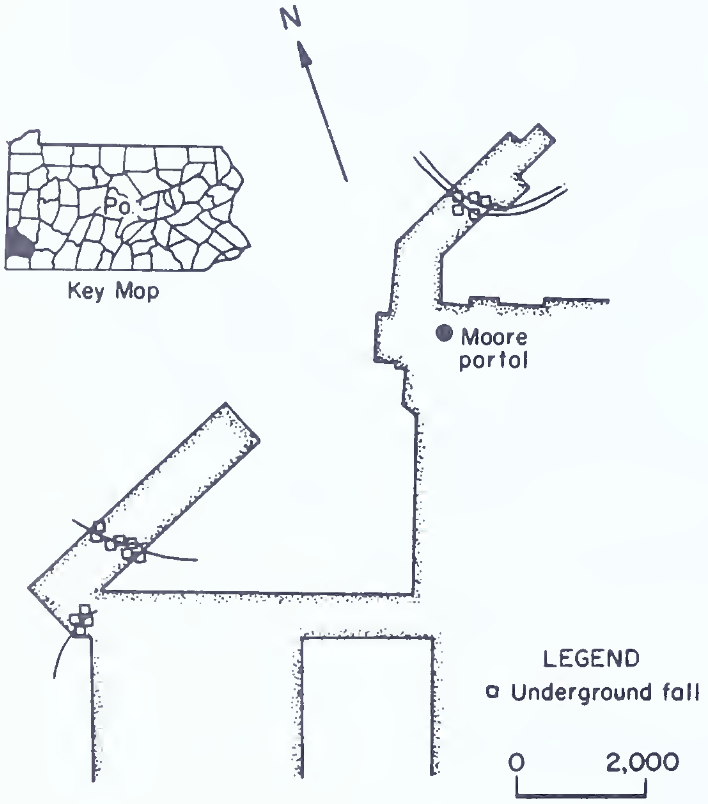

FIGURE 3. - Overlay of mine streams on surface related to underground falls.

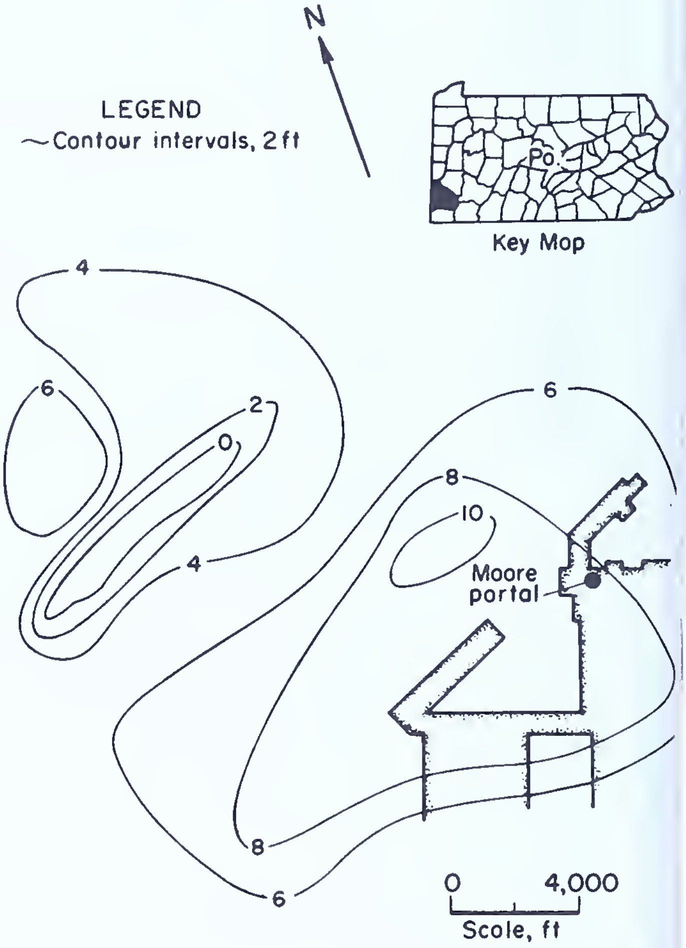

FIGURE 4. - Isopach of the wild coal interval over the Pittsburgh coalbed in the Marianna No. 58 mine.

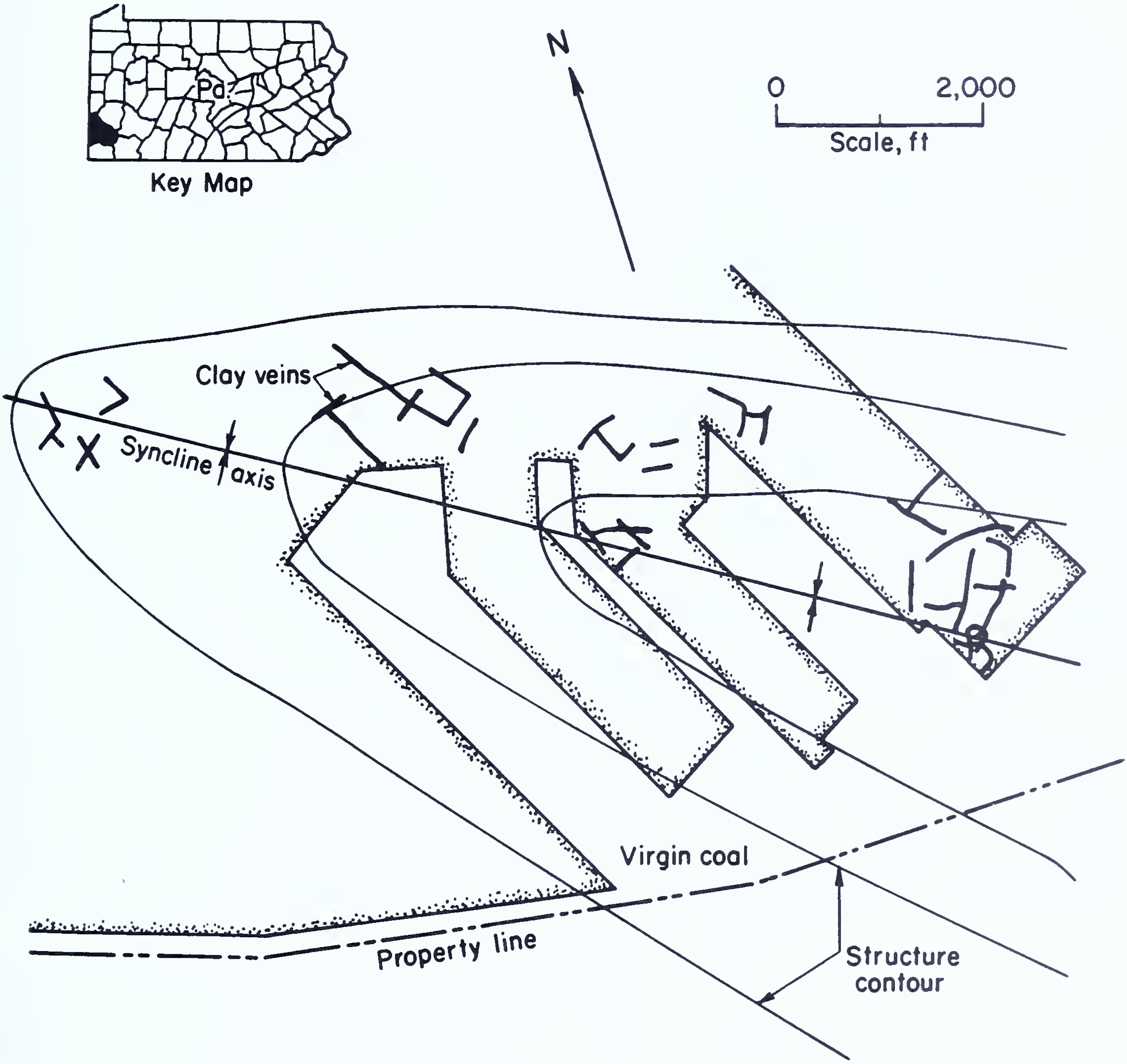

FIGURE 5. - Location of clay veins in the Marianna No. 58 mine.

already passed through the axis and were now encountering few clay veins, it was anticipated that when mining approached the axis of this syncline the occurrence of clay veins would increase.

Joints were measured on the surface (fig. 6) to evaluate correlations between the principal fracture directions underground and those on the surface. Correlation was excellent.

Lucerne No. 6 Mine

The mine is located approximately 2 miles southwest of Homer City, Pa., and operates in the Upper Freeport coalbed. A geological survey was conducted

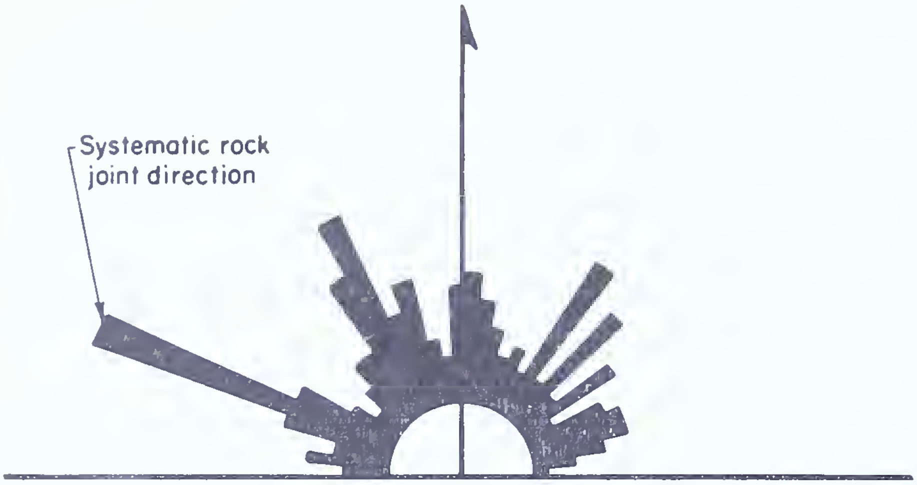

FIGURE 6. - Surface joint data above the Marianna No. 58 mine.

in March 1972. Cleat measurements showed a uniform pattern with the face cleat striking N56°W and the butt cleat N32°E. The dip was essentially vertical. The spacing of the face cleat, on the order of an inch, appeared to be uniform throughout the mine, except near the fault exposures, where the cleat was more closely spaced. The most significant geologic features of the mine were the fault exposures (fig. 7). They are low-angle thrust faults which offset the coal only a few feet along the fault plane (fig. 8). They affected both coal and roof rock, but did not appear to disturb the floor rock. These faults are not the result of sedimentary slumping. They occur at regular intervals and can be traced to the surface. When encountered by mining, the fault zones emitted large quantities of gas and water. There is insufficient evidence to conclude that all the faults observed were laterally connected. It is more probable that they were a group of small thrust faults occurring within a narrow thrust zone.

Aerial photographs were analyzed for linears. Two groups were identified, N47°E to N65°E and N25°W to N56°W, and interpreted as the regional joint pattern. In addition, poorly developed groups of linears striking N13°W to N05°E were present locally in 500-foot-wide bands at 6,000-to 7,000-foot intervals. The first of these lies about 2,000 feet west of the fault encountered in the West Mains. This may be the surface expression of the underground fault. If so, then additional faults or water zones could be expected as mine workings progress further to the west.

A structure map (fig. 9) of the base of the Upper Freeport seam, drawn from corehole data, shows a synclinal structure with axis bearing approximately N30°E and passing through the easternmost section of the mine. The largest part of the mine workings and reserves lies in the western limb of the syncline. The data points were too widely spaced to determine more than the gross structure of this area.

The core logs were studied with particular attention to the transition zone between the thick and normal Upper Freeport coal. The thick coal is east of the transition zone. This local thickening, limited in extent, is due to deposition. The thick Freeport coal is split from the main coal by a wedge of shale that thickens to the southwest. The general strike of the transition

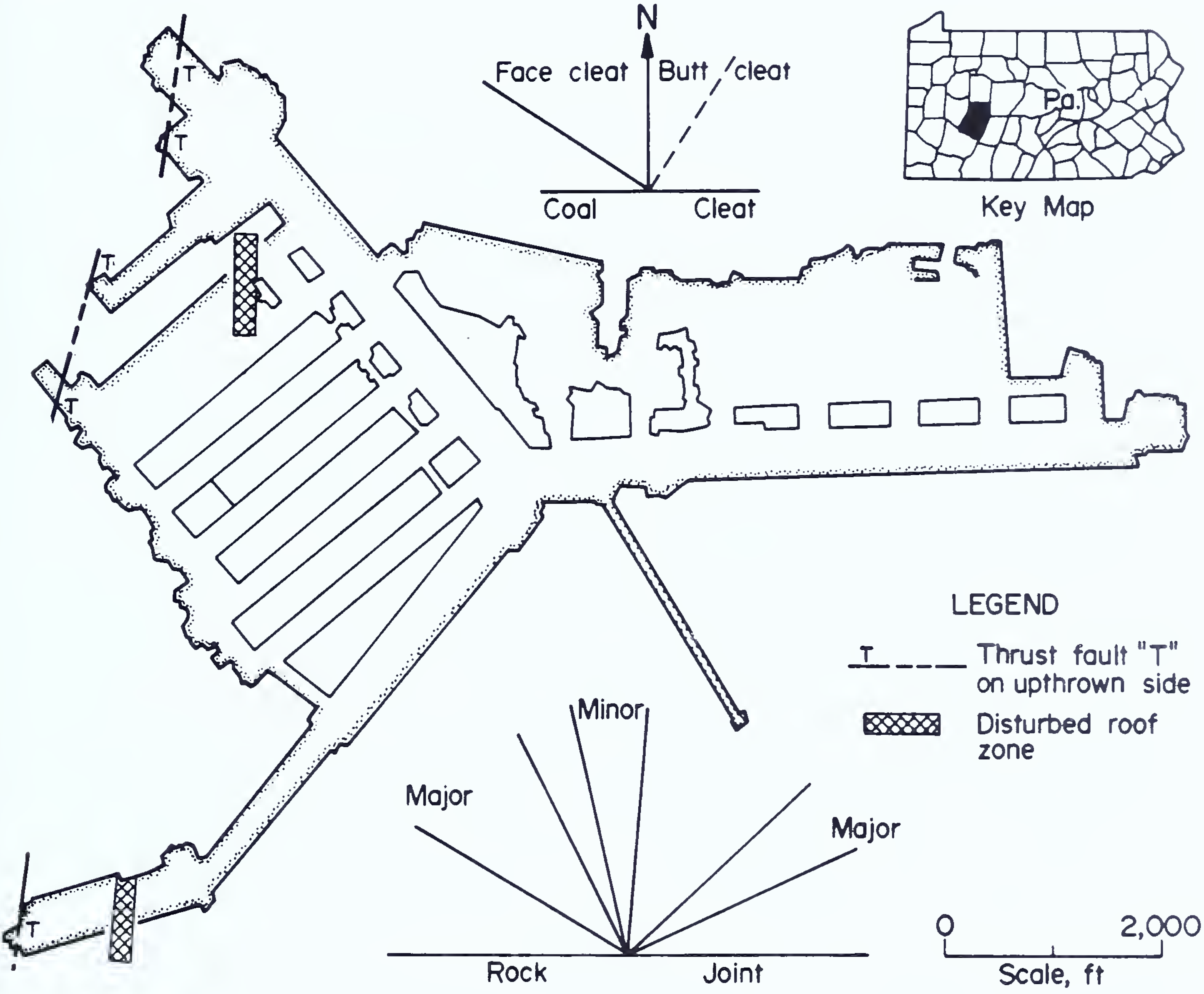

FIGURE 7. - Fault exposure at Lucerne No. 6 mine.

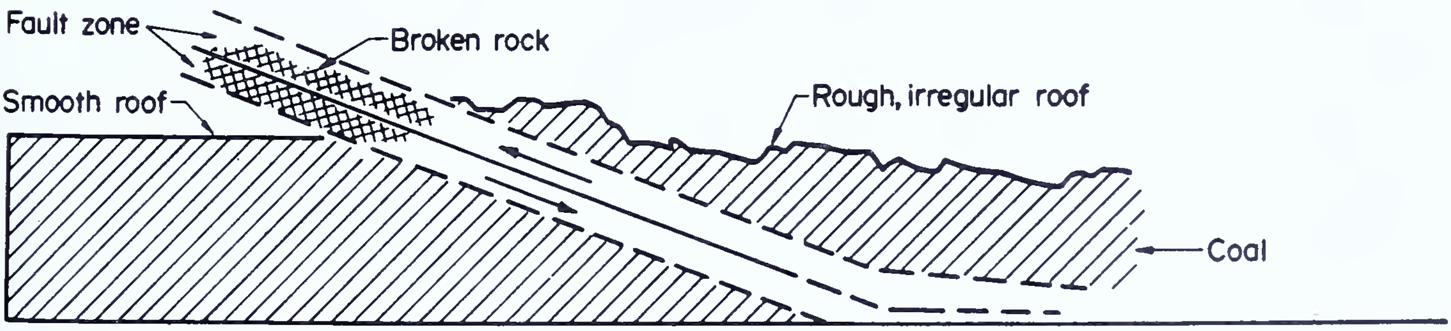

FIGURE 8. - Generalized sketch of typical thrust fault exposure at the Lucerne No. 6 mine.

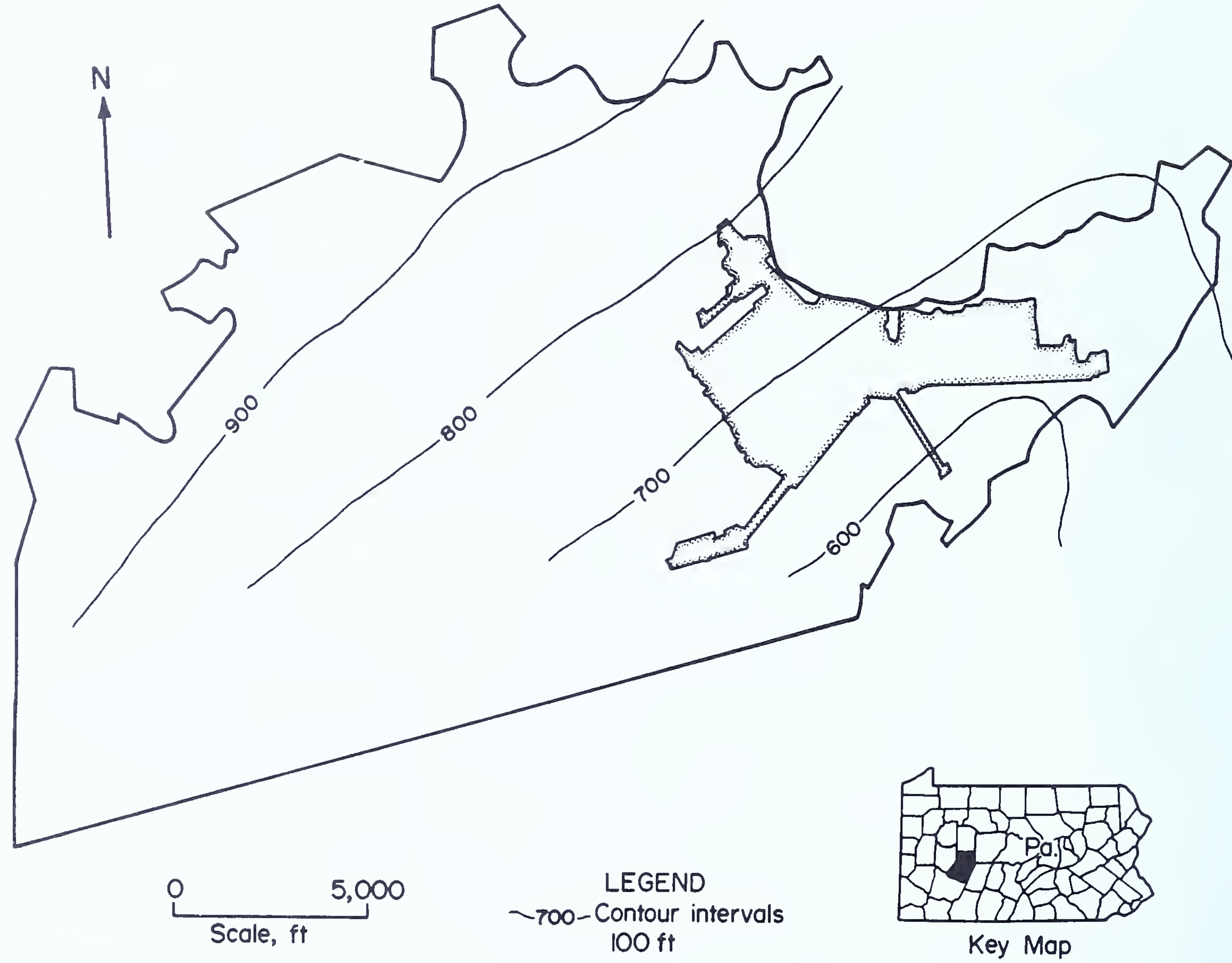

FIGURE 9. - Structure map drawn on the base of the Upper Freeport coalbed, Lucerne No. 6 mine.

zone is N30°W. This is illustrated by the fence diagram (fig. 10) constructed from the core log descriptions of the first 40 feet of rock above the coal. Within this interval, sandstone is present throughout almost the entire area. This sandstone is separated from the coal locally by shales and sandy shales. Its large lateral extension makes it a probable water and gas reservoir. Thick sandstone directly overlying coal often exhibits deformations due to compaction which appears locally to be thrust faults, but this was not the case here. The core logs were examined for records of broken rock, but they yielded no pattern indicative of possible fault zones.

Somerset No. 60 Mine

The mine is located several miles west of Ellsworth, Pa. It is working in the Pittsburgh coalbed and produces 1.5 MM ft^3 of gas per day. A geological survey was conducted in February 1973.

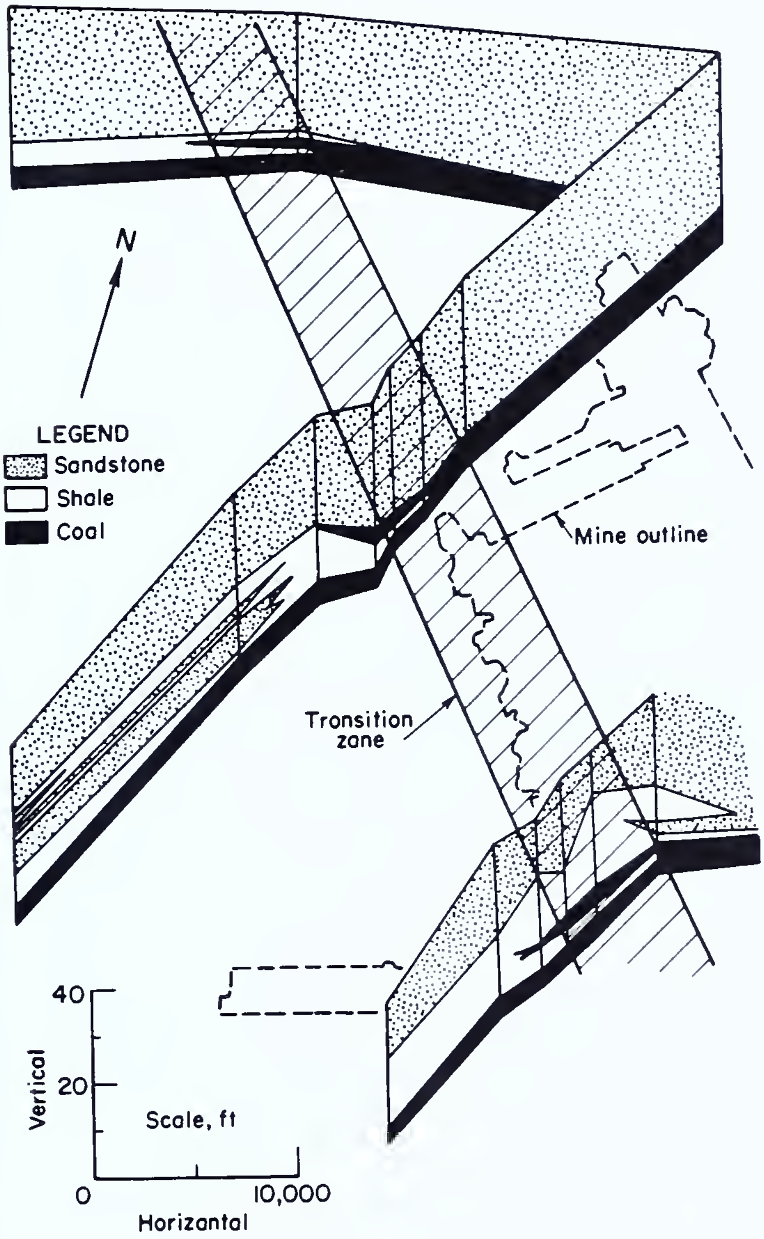

FIGURE 10. - Fence diagram of strata above the Upper Freeport coalbed, Lucerne No. 6 mine.

The cleat system is orthogonal; the main direction of the cleat is N57°W (face) and N30°E (butt). The coal cleats are well developed with spacing ranging from 1 to 6 inches. Mining had been parallel to the cleat, but at present is 45° to the previous workings which gives a more stable roof.

The immediate roof is generally coal because a slickensided claystone or draw slate, generally 12 inches or less, overlying in the coal, is removed during mining, leaving the stable rider coal. Roof falls show the weak strata to be either micaceous sandstone with thinly interbedded shale, or alternating coals and slickensided claystones.

The measured rock joint orientations were between N57°W and N75°W, corresponding roughly to face cleat orientation.

The structural map of the area, based on the Pittsburgh coalbed, shows that mining is preceding down the northwest flank of the Amity anticline towards a syncline (fig. 11). Water is reportedly accumulating at the face of entries being driven to the northwest. This condition may be expected as long as the entries dip into the working face. Once they advance on the axis of the syncline, the floor will dip away from the face and water should no longer accumulate there.

A fence diagram of the 40 feet of strata immediately above the main bench of the Pittsburgh coalbed (fig. 12) in the 84 field directly to the west of the present mining was constructed, because of the occurrence of sand channels cutting out coal in the western part of the active mine workings. The data were taken from the company core logs. There was an abrupt change in this interval from north to south, with shale predominating in the north and sandstone in the south. The abruptness of this change is shown by drill

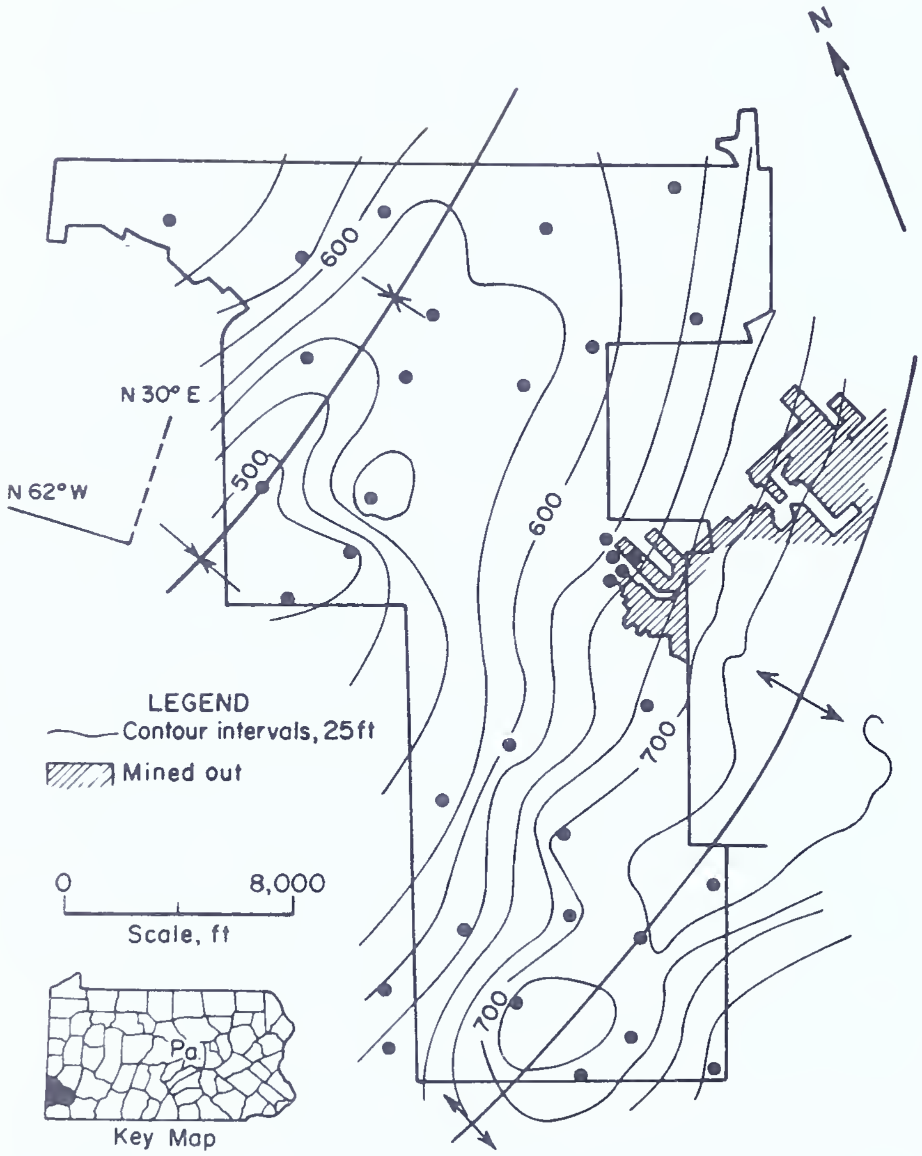

FIGURE 11. - Structure map drawn on the base of the Pittsburgh coalbed at Somerset No. 60 mine.

holes TH1 and TH2 (fig. 13) drilled 620 feet apart. The change in lithology is due to stream erosion of strata that were originally deposited over the coalbed in the same way as in the northern part of the area. Subsequently, sand was deposited in these erosion channels. The depth of erosion varied from place to place so that the coal is only removed locally. The thinner the interval between the coalbed and the overlying sandstone, the greater the probability that erosion will affect the coalbed. A map based on present drill hole data shows areas where cutouts may be expected (fig. 14).

Overlying the main bench (mined portion) of the Pittsburgh coalbed is an interval of variable thickness composed of alternating slickensided claystones and coals (fig. 15). The interval has very little strength and can fall, causing gas emissions as well as haulage problems. Most mines prefer to anchor roof bolts in the more competent rock above this interval. Figure 15 can be used in a general way to determine the minimum length of bolt that would be necessary to bolt through the interval in any given area.

The geological data from core holes spaced more than 3,000 feet apart are difficult to correlate. More closely spaced drilling is necessary to delineate the northern limit of the sandstone. This zone is of particular importance in mining because it represents the northern limit of stream erosion of the strata overlying the Pittsburgh coalbed. Zones of abrupt lithology change can also coincide with areas of unstable roof, high gas emission, and related mining problems.

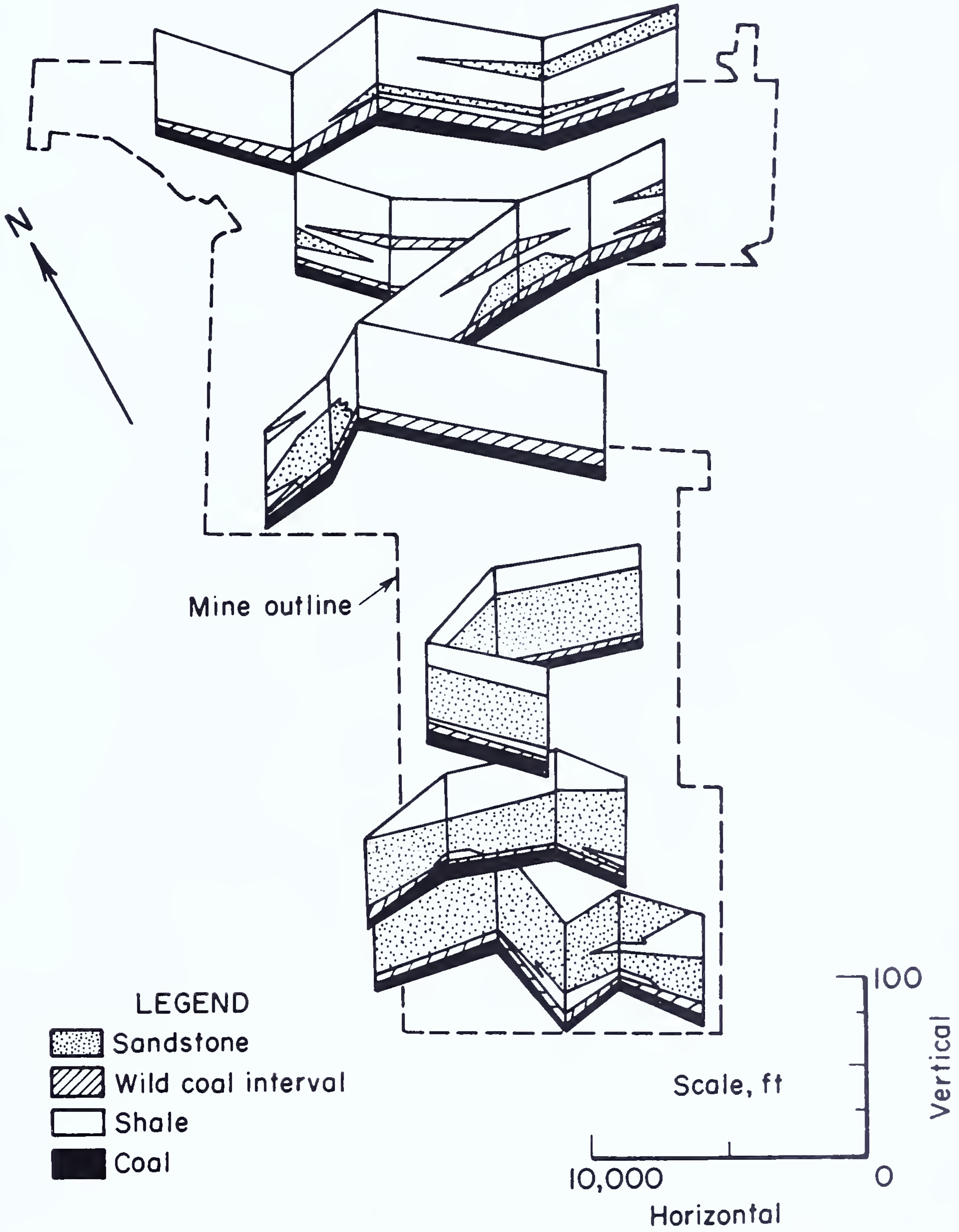

FIGURE 12. - Fence diagram of strata above the Pittsburgh coalbed, Somerset No. 60 mine.

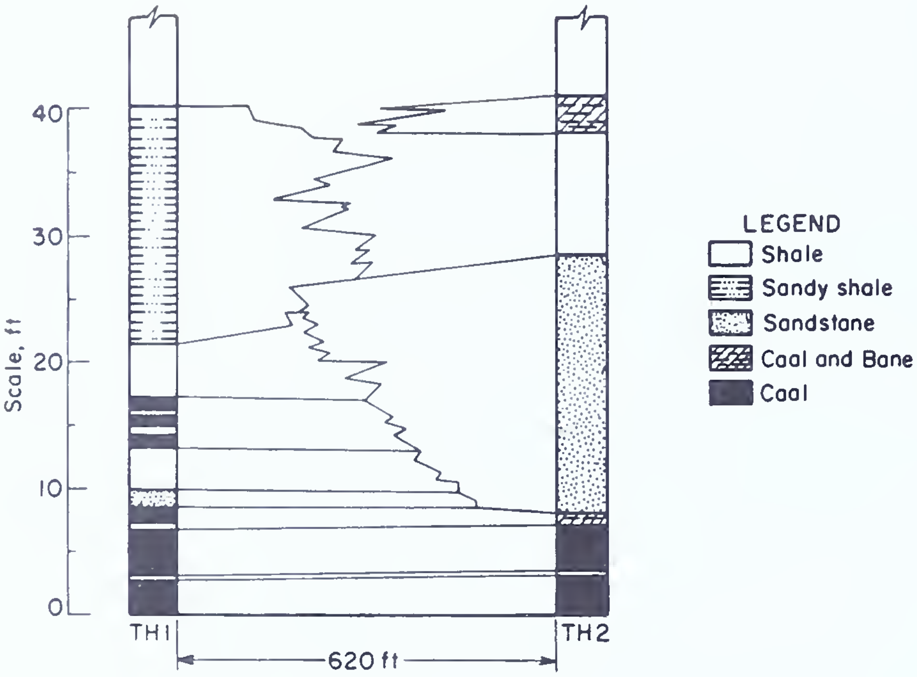

FIGURE 13. - Lithologic change between drill holes TH1 and TH2.

Federal No. 2 Mine

The mine is located in the Batelle district of Monongalia County, W. Va., where the Pittsburgh coalbed averages 7-1/2 to 9 feet thick. The mine produces an average of 8.1 MM ft^3 of gas per day. The rocks above the coal are sandstones, sandy shale, shales, limestones, and coals. The present mine outline is shown in figure 16.

In August 1970, a geological reconnaissance and a fracture survey were made of the mine. The company had no topographic map showing the location of the coreholes. The drillers' log data were plotted on an overlay of the

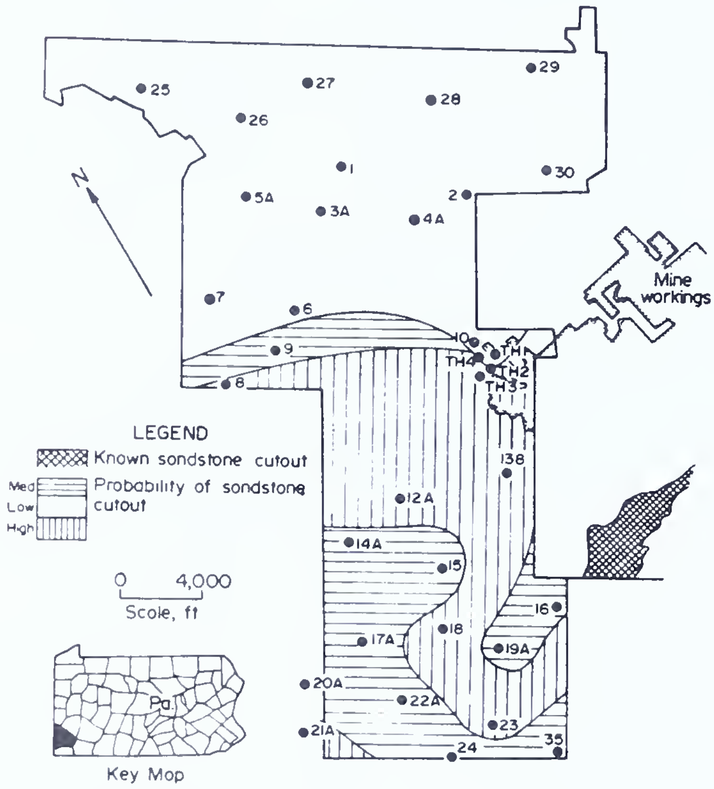

FIGURE 14. - Location of possible sand channel washout, Somerset No. 60 mine.

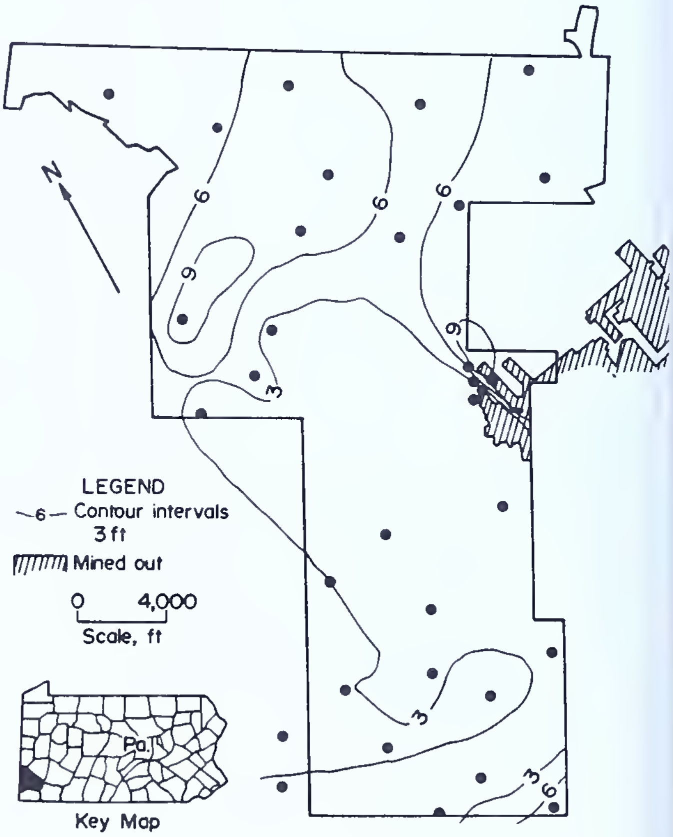

FIGURE 15. - Isopach of the draw slate unit above the Pittsburgh coalbed, Somerset No. 60 mine.

Blacksville and Mannington 15-minute quadrangles, using the drillers' location descriptions. The surface elevation for each hole was roughly determined from the contours on the topographic maps.[4]

An isopach of the interval between the Pittsburgh and Redstone coalbeds showed a thinning to the southwest; the interval thickness ranged from 22 to 42 feet.

A structure map (fig. 17) shows the axis of the Waynesburg syncline passing through the western extremity of the mine property. The Pittsburgh coalbed dips generally west-northwest towards the axis. The Belle Vernon anticline and the Whitely syncline are well developed northeast of the mine area. In the central portion of the mine property, there is a local upwarping which interrupts the gentle westerly dip.

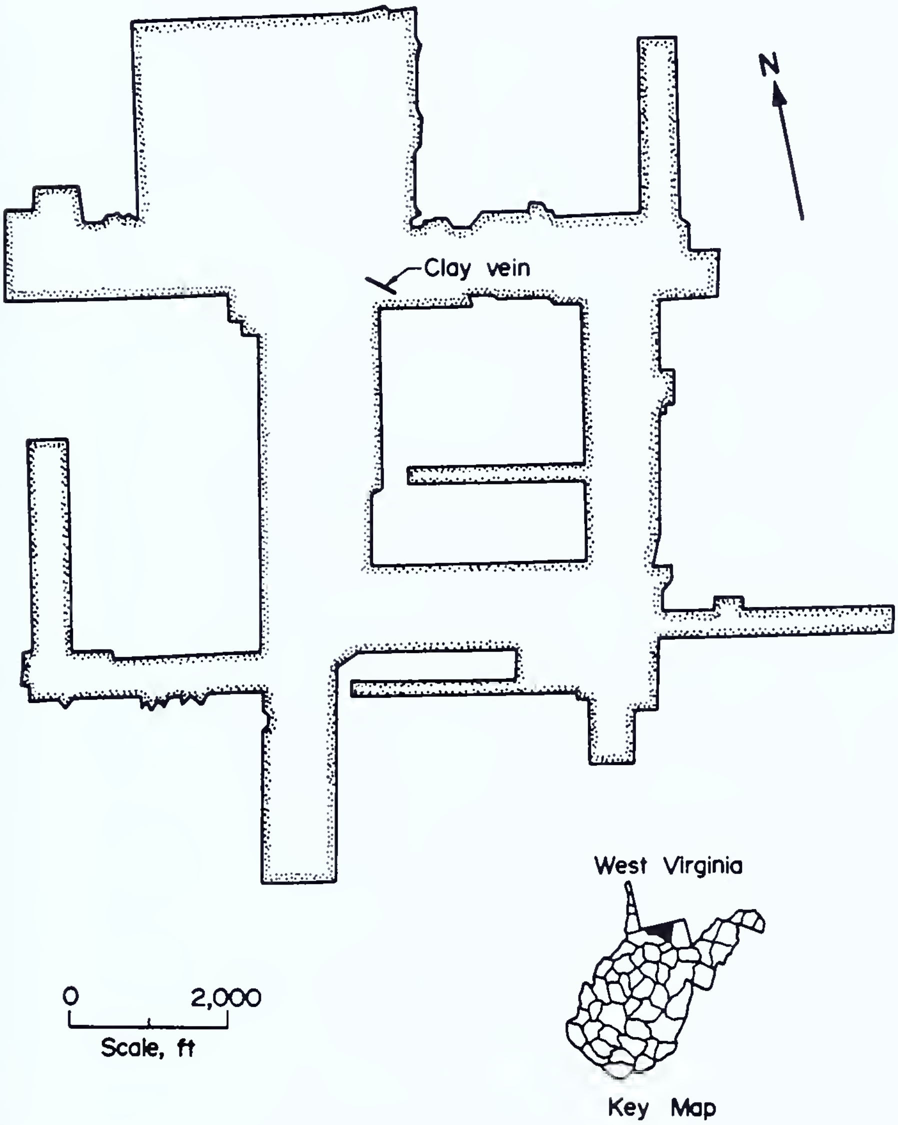

FIGURE 16. - Outline of the Federal No. 2 mine.

Analysis of the cleat data showed uniformity within the present mine development. The face cleat strikes N68°W, the butt cleat strikes N22°E, and the dip is essentially vertical. A series of slump fractures were observed in the East Bleeder, and one clay vein (fig. 16) approximately 150 feet long extends from the roof 2 feet into the coalbed near the mouth of the East Mains. The slump feature may be due to some local channel erosion or to differential compaction. Geologically related mining problems are methane emissions and roof instability, which go hand-in-hand in many instances. Driving north-south tends to develop high gas by intersecting face cleats. Roof control problems are probably due to bolting into the incompetent alternating coals and shales (draw slate interval).

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[4] The drillers' location descriptions were general, and with the high relief in the area, it is possible for elevations to be in error by as much as 50 feet.

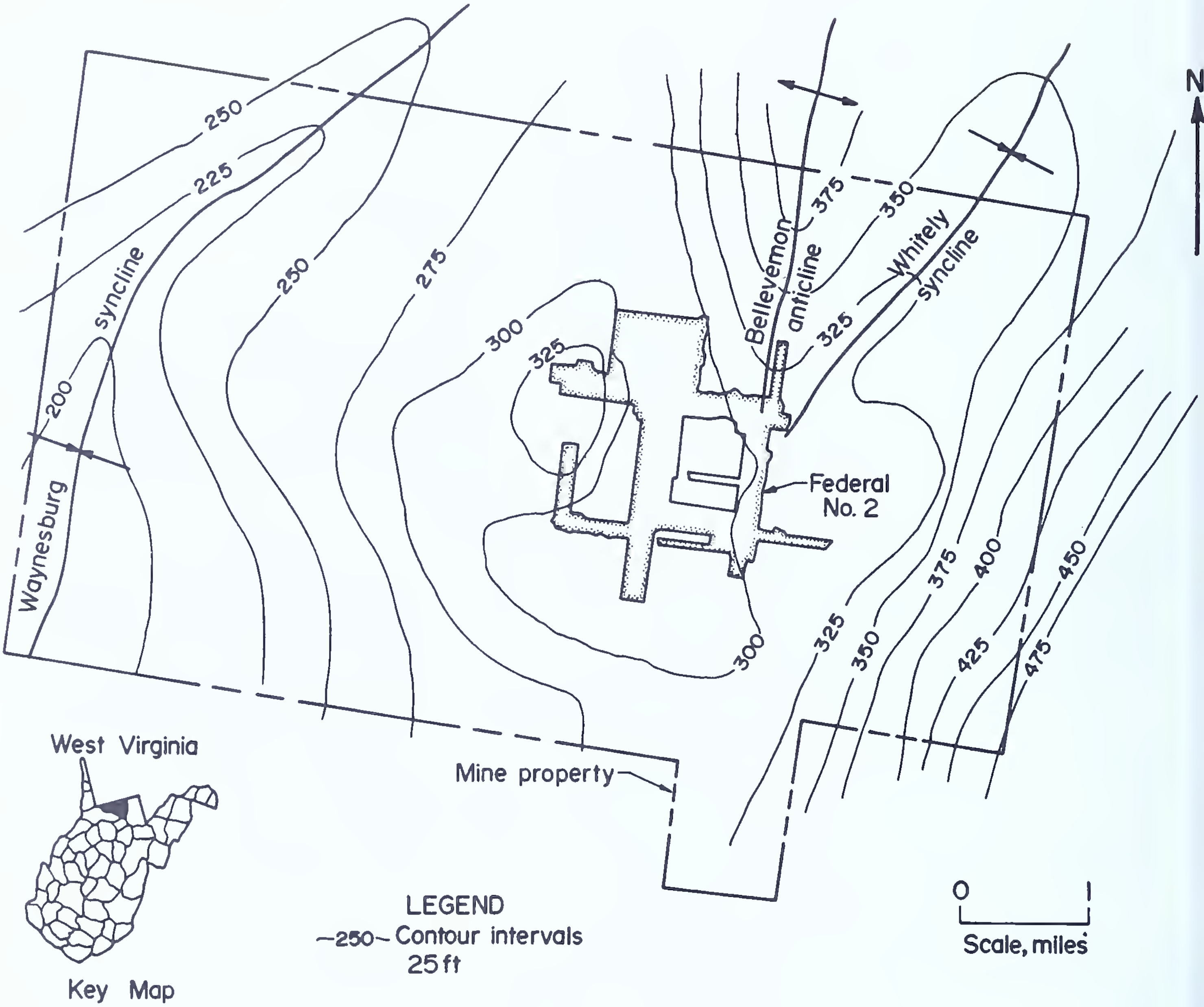

FIGURE 17. - Structure map drawn on the base of the Pittsburgh coalbed, Federal No. 2 mine.

Howe Mine

The mine is located 6 miles south of Poteau, La Flore County, Okla. It is on the south side of the Arkoma Basin, which is described as a synclinorium. Figure 18 shows the generalized structure of the Lower Hartshorne coalbed and the two major structures present in the area--the Howe anticline and Poteau syncline--with the cleat orientations. The Hartshorne coalbed consists of an upper bench averaging about 32 inches in thickness, below which there is a shale parting up to 24 inches thick, followed by several thin layers of usually impure coal laminated with black, carbonaceous shale.

A panel diagram (fig. 19) constructed from core logs of the test holes drilled by the company shows that the immediate roof over most of the property is sandstone. According to Bureau research, the absence of shale between the coal and sandstone greatly increases the probability of sandstone channels.

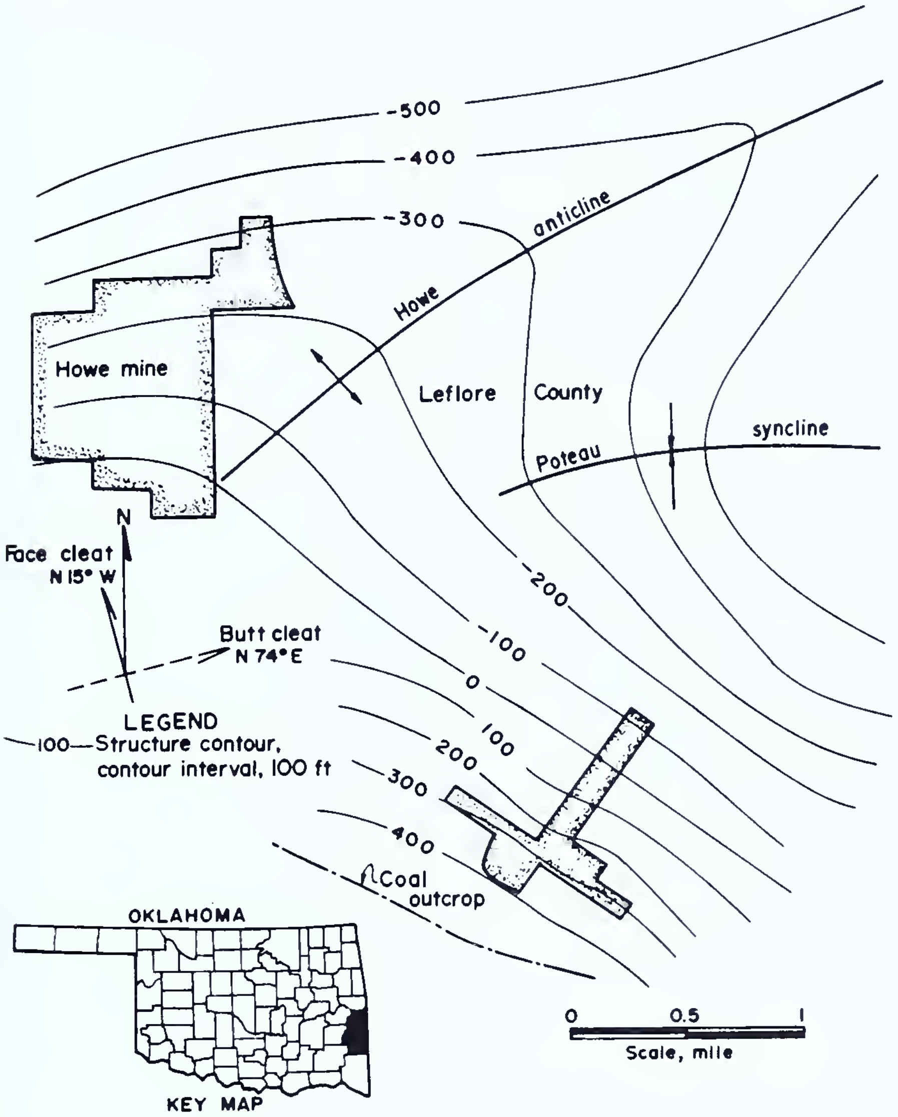

FIGURE 18. - Structure map drawn on the base of the Lower Hartshorne coalbed, Howe mine.

The coalbed within the mine dips about 7° in a northerly direction. Locally, dips between 2° and 12° have been recorded within the mine. The minor apparent folding is probably due to differential compaction between the sands and shales that forced the Lower Hartshorne coal to conform to the irregular shapes of the sand channel bottoms, where they come in contact with the coalbed. Where the coalbed and sandstone were separated by sufficient shale, the shale acted as buffer and the coalbed was not deformed.

Coal cleat orientations were measured throughout the mine, as were roof and floor rock joints. Orientations of rock joints were measured at surface outcrops. The coal (fig. 18) displayed a bimodal face cleat N15°W and N25°W, and a single butt cleat approximately perpendicular to these at N74°E. There was only one primary joint direction in the roof and floor rocks in the mine, N23°W. This is parallel to one mode of the bimodal face cleat. The surface rocks have two joint directions approximately 90° apart, N15°W and N72°E. These directions correspond closely with face and butt cleats in the Hartshorne coalbed.

The inclination of the coalbed makes it very difficult to work. Where the coal is overlain by sandstone, the bed is undulatory so that the continuous miner must be backed up and floor rock taken to obtain a proper angle of attack. The presence of shale roof to the west indicates that the undulation of the coalbed may disappear in this direction.

Water is a nuisance but does not affect production significantly. It appears to enter the sands from older mine workings and the outcrop, and migrate down dip to the present mine workings. This has been alleviated by pumping out the abandoned workings up dip. Possibly where the immediate roof is solid shale, the water influx will be less, but it is believed that anything short of sealing the roof will not eliminate the water.

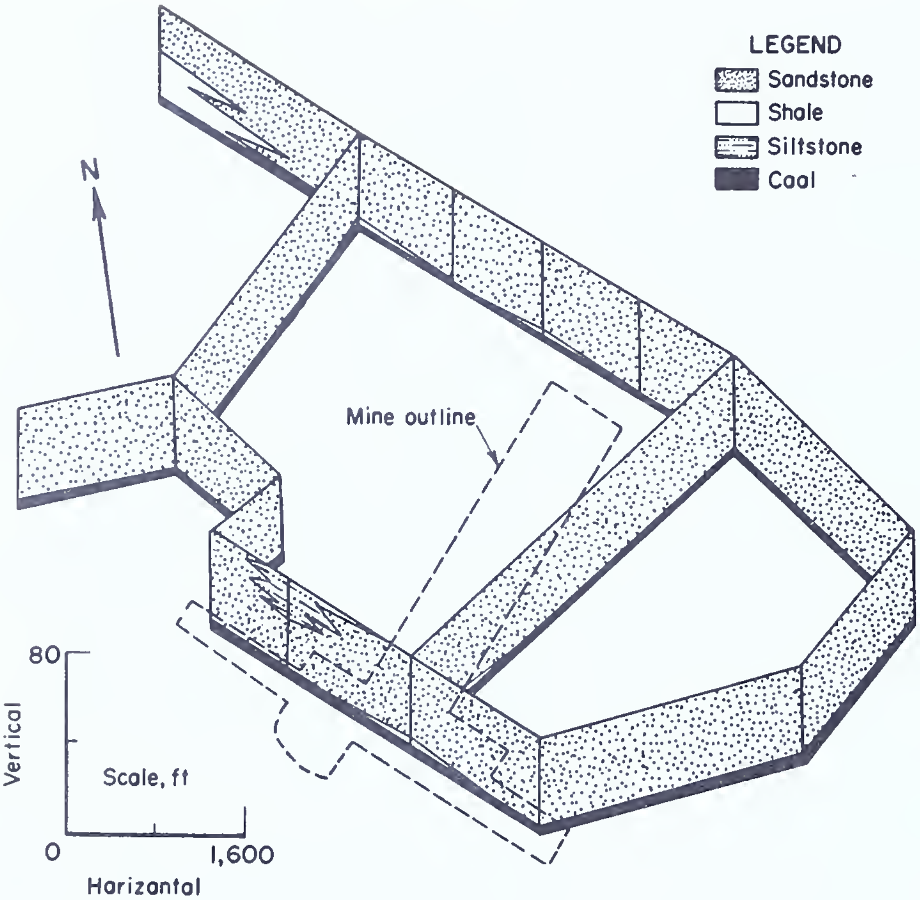

FIGURE 19. - Fence diagram of the strata above the Lower Hartshorne coalbed, Howe mine.

The Arkoma Basin is a prolific gas producer. Practically every anticlinal structure penetrated by drilling has produced gas from porous and permeable strata. This would indicate that the gas problem in the Howe mine is not a simple one, and Howe is a gassy mine. Most of the gas appears to come from the coal, but there is occasional bubbling from the floor. Until detailed measurements can be made, both roof and floor rocks must be considered as possible gas producers.[5]

Beatrice-Pocahontas Mine

The mine is located in Buchanan County, Va., in the gently folded Allegheny Plateau Province, approximately 8 miles northeast of the Valley and Ridge Province and less than 15 miles northwest of the Pine Mountain overthrust block. It is operating in the Pocahontas No. 3 coalbed and produces an average of 13.2 MM ft^3 of methane per day. A geologic survey was conducted in April 1973.

A shear fault (fig. 20) of 2 to 18 feet vertical displacement, but unknown horizontal displacement, was encountered within the mine, trending northwest-southeast at 145° and 155° alinement and dipping 60° to the southwest. Slickensides on the faulted rock surfaces were parallel to bedding, indicating that the major movement was horizontal rather than vertical. Further evidence from surface exposures, together with data from mine operations in seams above the Pocahontas No. 3, permitted the delineation of a strike-slip fault at least 9 miles long. A more detailed study of the area using side-looking airborne radar (SLAR) was done by Elder (1).

Cleat measurements showed face cleat trending N18°W and butt cleat trending N67°E. On the northeast side of the fault, a rotation of the cleat (fig. 21) indicated that this side had acted as a buttress against which the southwest block moved.

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[5] This survey was made in March 1971. This mine has since closed down, but there is a strong possibility that it will reopen in 1975.

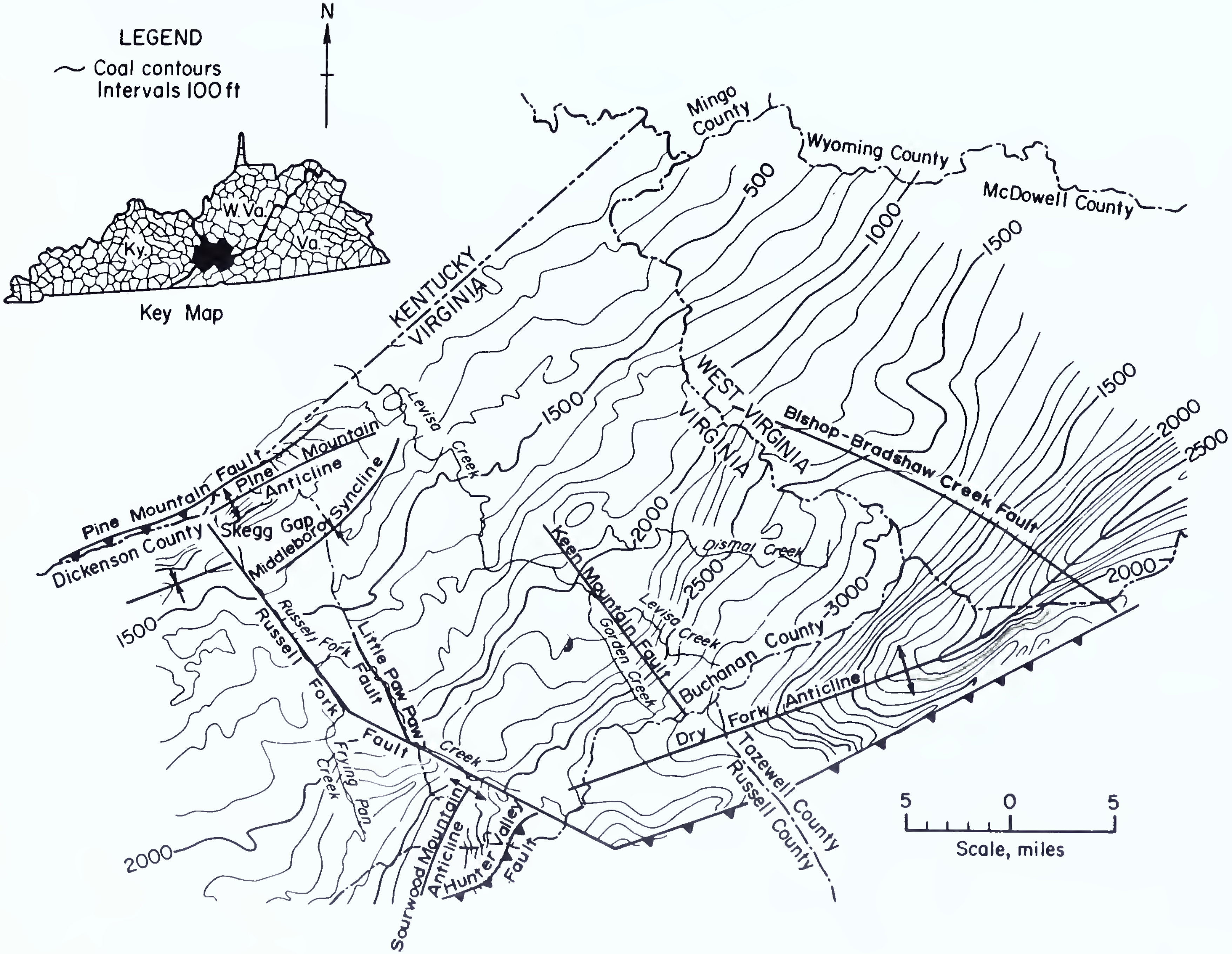

FIGURE 20. - Map of Keen Mountain fault in the Pocahontas No. 3 coalbed, Beatrice-Pocahontas mine.

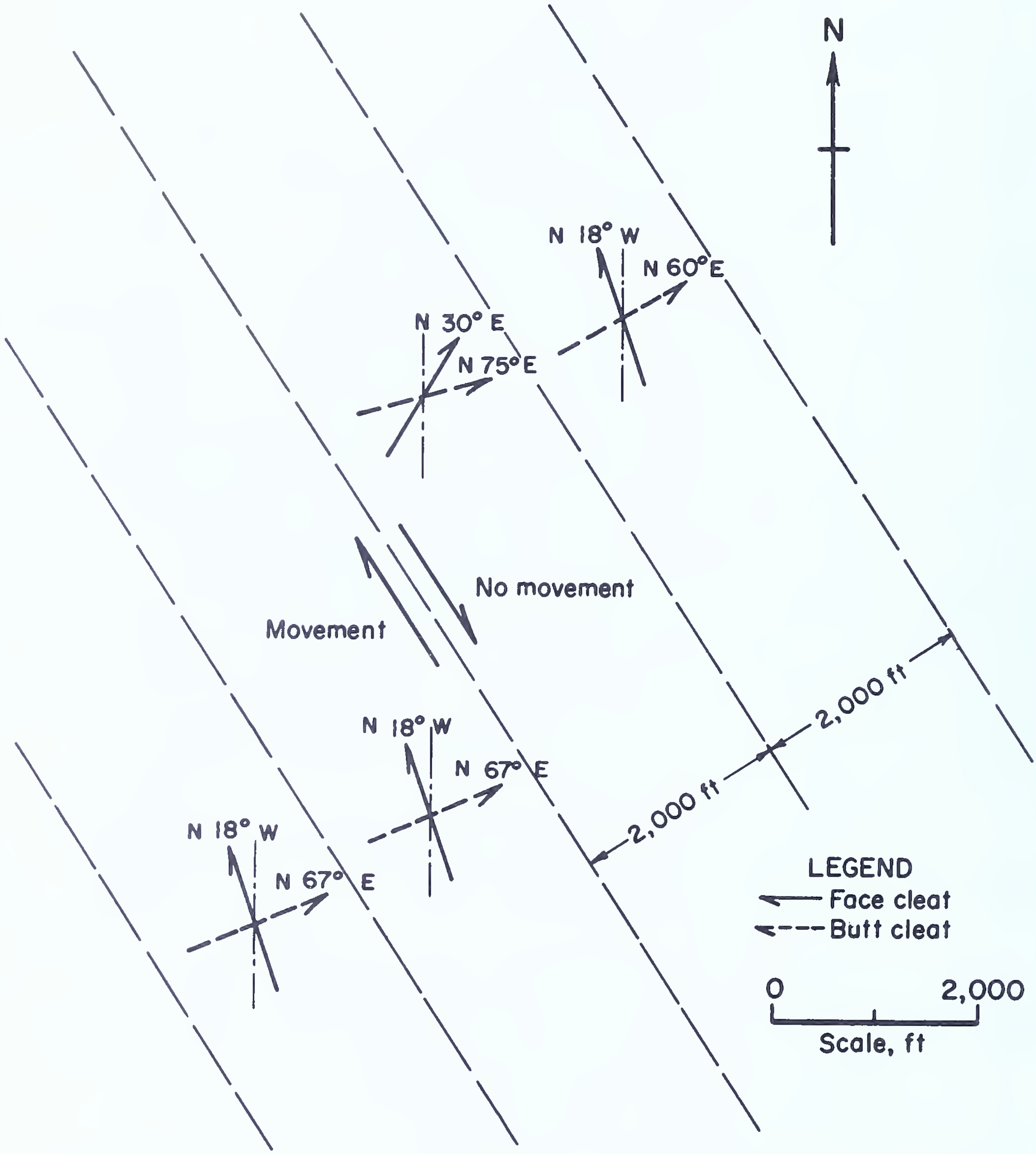

FIGURE 21. - Cleat rotation in relation to shear fault, Beatrice-Pocahontas mine.

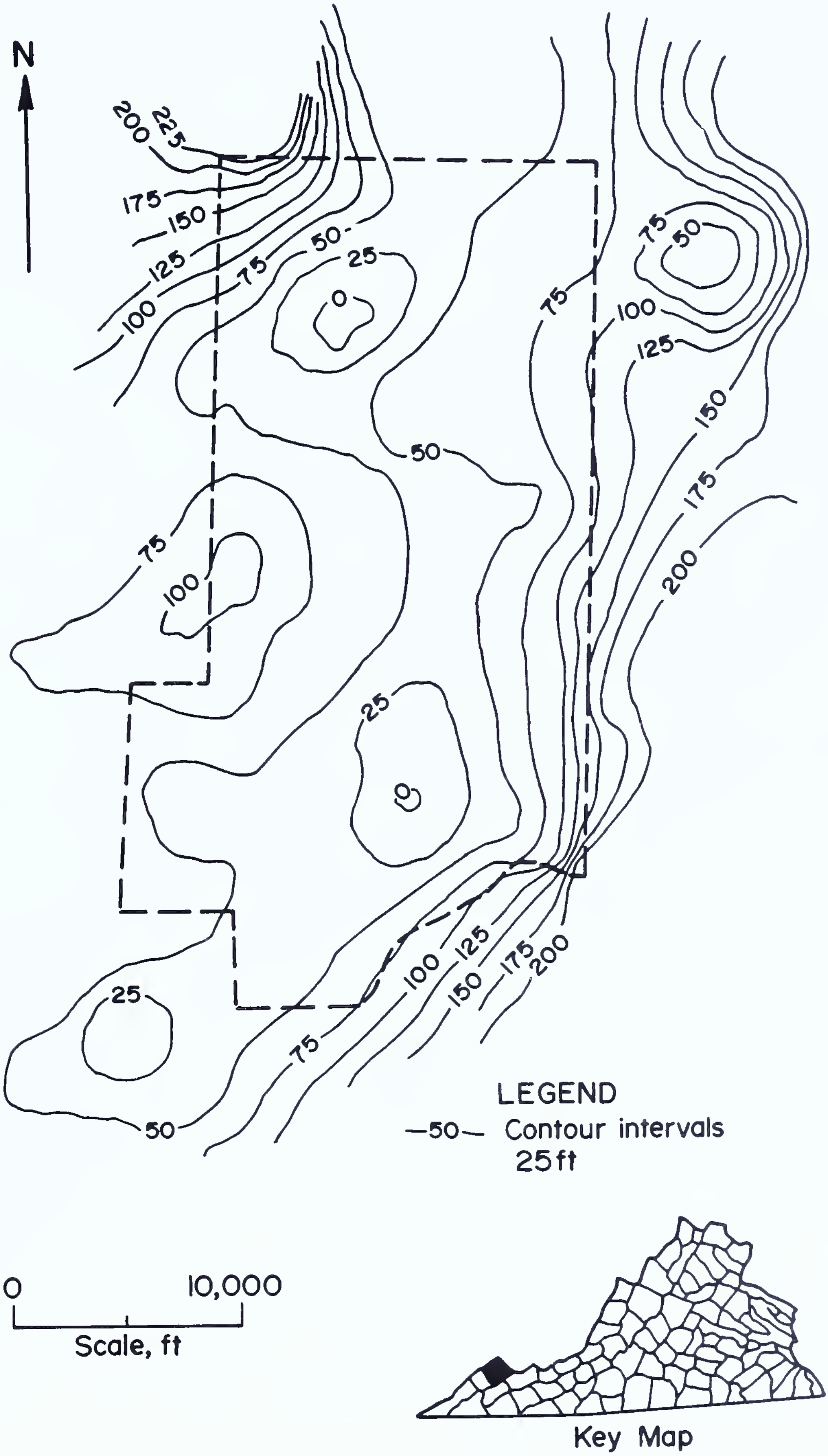

FIGURE 22. - Structure map drawn on the base of the Pocahontas No. 3 coalbed, Beatrice-Pocahontas mine.

According to a structure map (fig. 22), the mine is located on the flank of a monocline with a west-southwest dip. A fence diagram (fig. 23) showed two possible sandstone channels, one running southeast and the other northeast. The one trending southeast has already been encountered in mining and did cut out the coal. The one trending northeast has not yet been reached, but it is expected to cause much the same type of problem as the first one.

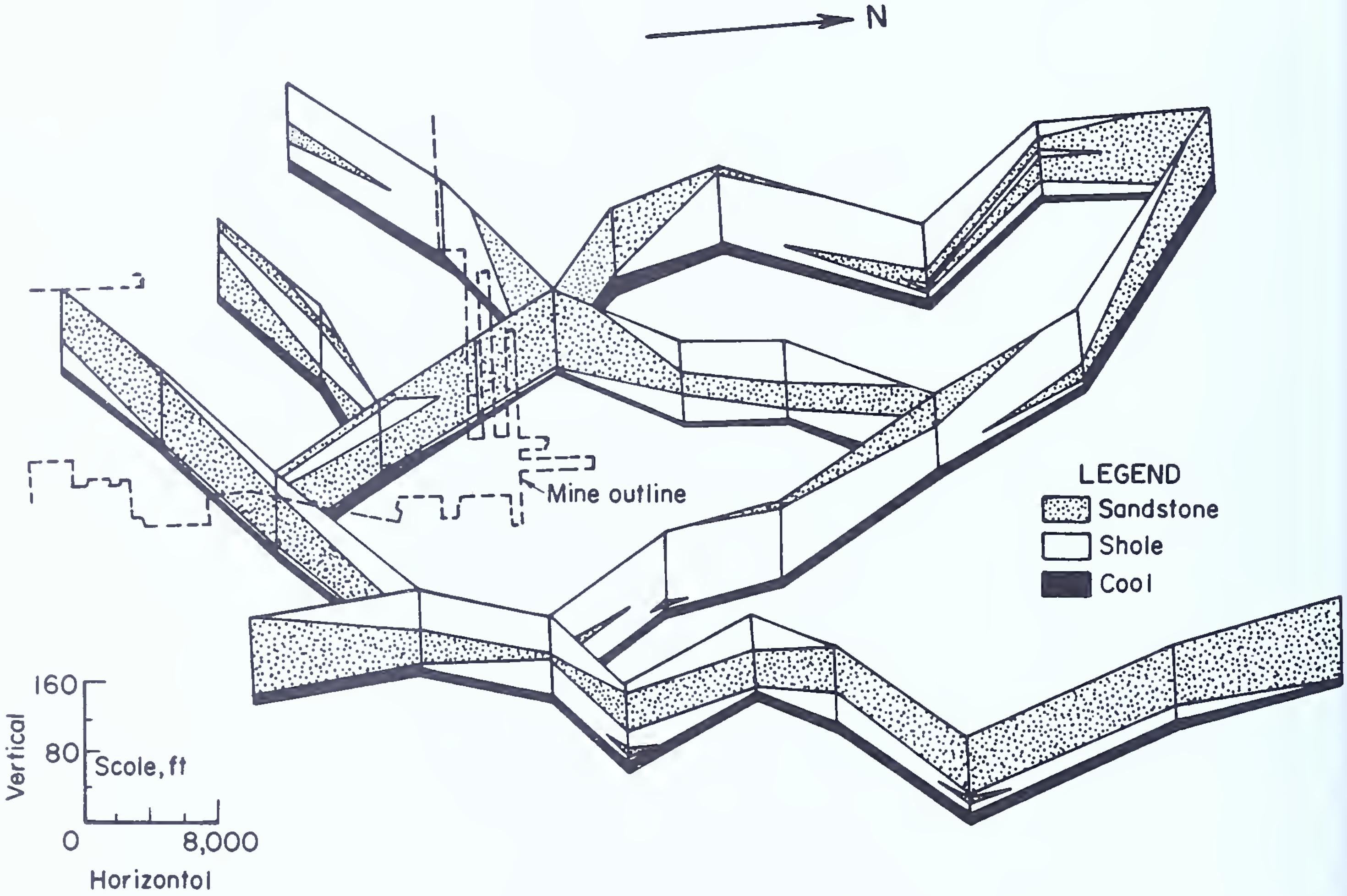

FIGURE 23. - Fence diagram of the strata above the Pocahontas No. 3 coalbed, Beatrice-Pocahontas mine.

During the survey, it was noted that washouts occurred with massive sands, and a majority of the falls observed had micaceous sands composing the fall unit. A map of the type of sandstone (massive or micaceous) found above the coal (fig. 24) should anticipate such problems and make it possible to modify mining techniques before problem zones are encountered.

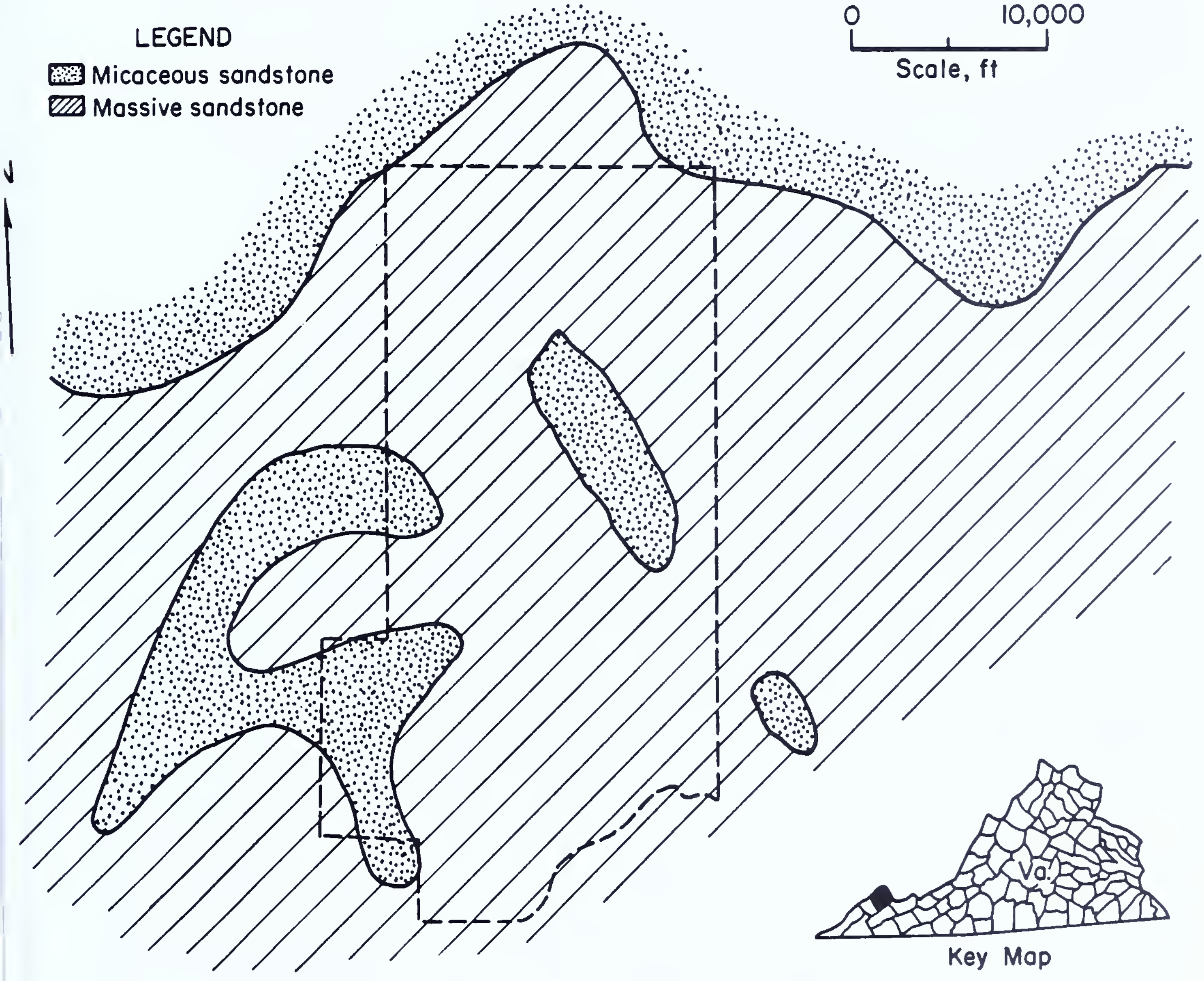

FIGURE 24. - Nature of sandstone above Pocahontas No. 3 coalbed, Beatrice-Pocahontas mine.

An isopach map (fig. 25) of the coal thickness was prepared to determine if any washouts could be located. A second isopach from the coal to the sandstone above (fig. 26) was constructed to determine if the roof falls and gas content correlated with proximity to the sands and as an additional aid in locating washouts and channels.

Finally an overburden isopach (fig. 27) was drawn to verify a Bureau of Mines theory that relates the amount of gas to the thickness of the overburden.

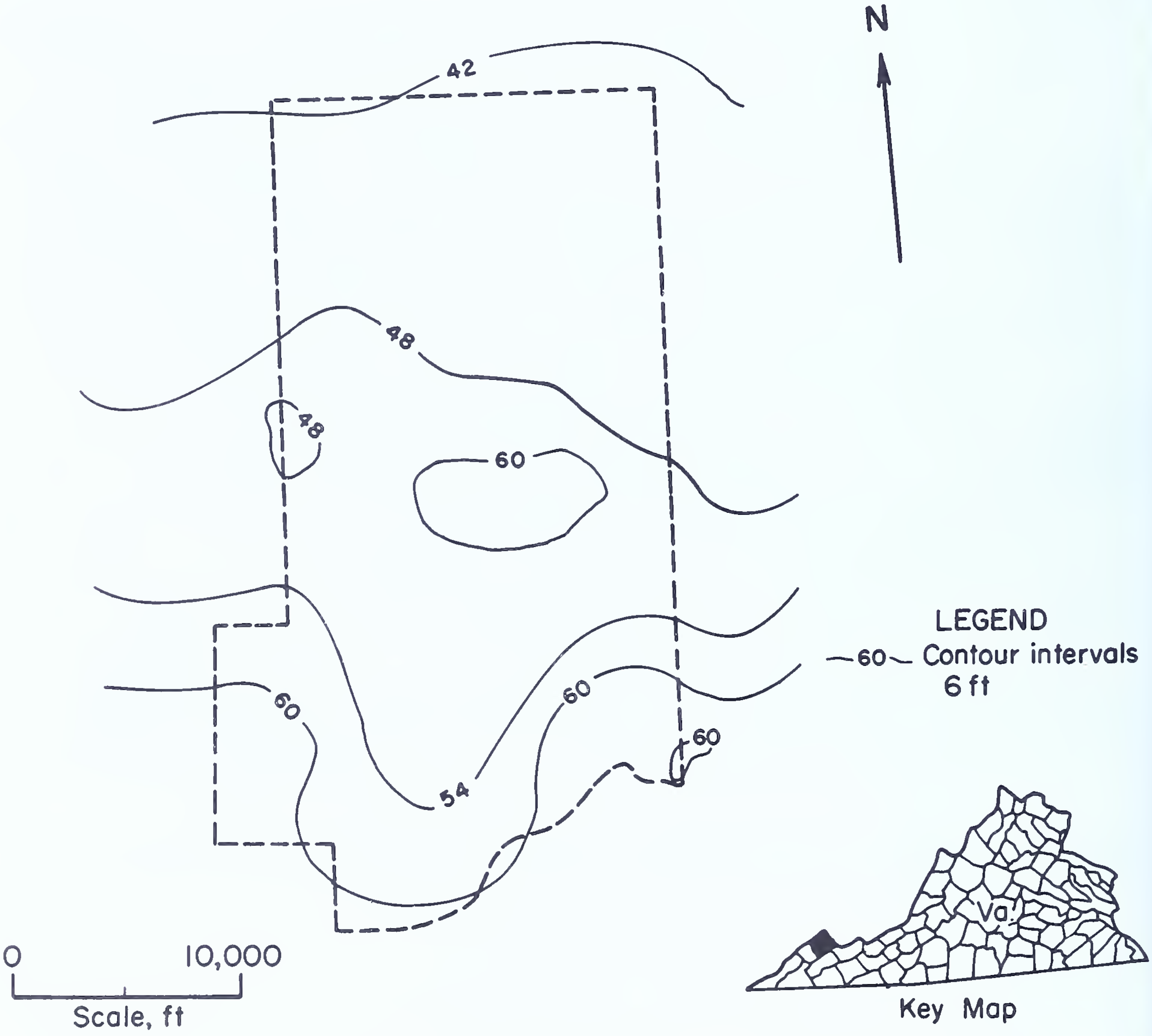

FIGURE 25. - Isopach of Pocahontas No. 3 coalbed (inches), Beatrice-Pocahontas mine.

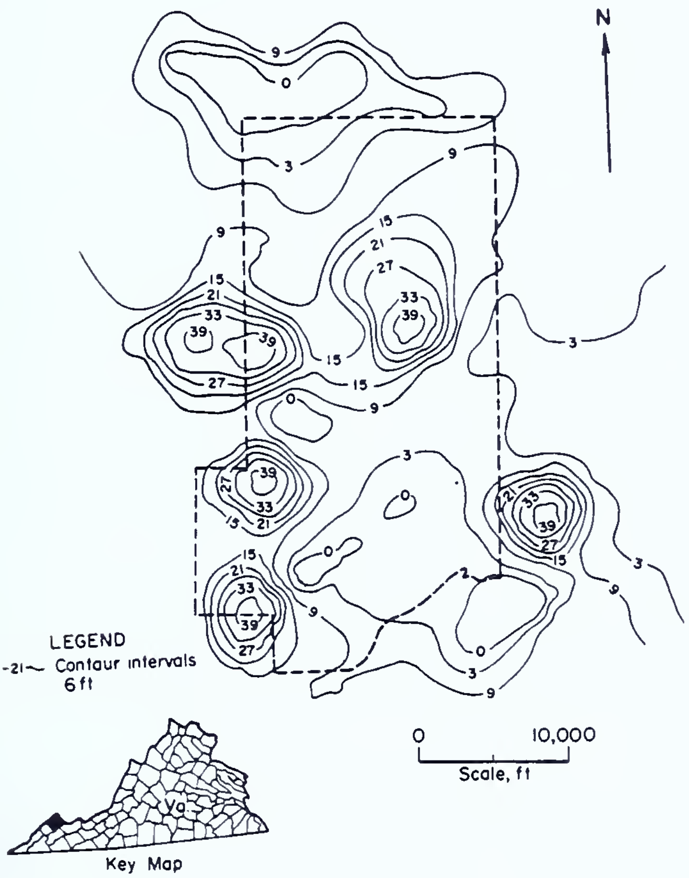

FIGURE 26. - Isopach of interval between Pocahontas No. 3 coalbed and sandstone above Beatrice-Pocahontas mine.

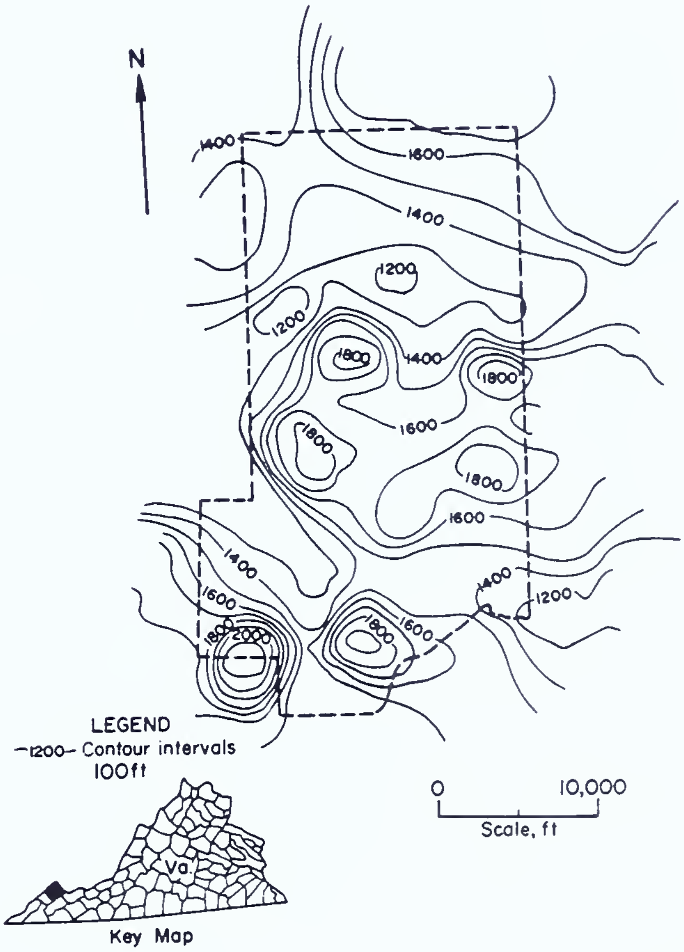

FIGURE 27. - Overburden isopach map of interval from Pocahontas No. 3 coalbed to surface, Beatrice-Pocahontas mine.

SUMMARY

The knowledge gained from geologic investigations of mines can help control many underground problems. It is of primary importance for the coal companies to have accurate core logs from closely spaced drill holes. A grid system with not more than 3,000-foot centers, and preferably with 2,000-foot centers, is recommended for obtaining useful geologic information.

Basic to the investigation of the various types of mining problems encountered is the construction of geologic maps and fence diagrams. They can help predict areas of probable roof instability and trends of sandstone channels that may cut through the coalbed.

Clay veins can be mapped in underground surveys and their trends predicted into future areas of mining. Predicting trends of clay veins has been somewhat less successful than predicting sandstone channels.

The sources of water accumulations can be evaluated for possible geologic influence. Fault zones and roof fracturing have been shown to induce the production of water, as well as gas, into a mine.

A detailed joint pattern of the area above a mine can be established and its relationship to coal cleat direction and roof fractures underground evaluated. Excessive spalling of ribs when mining is with the cleat direction can sometimes be corrected by a 45° rotation in the mining direction. Joint information can also be of benefit when degasification wells are planned for virgin coal areas. Local deviations in the joint and cleat directions can be an indicator of geologic irregularities that might adversely affect mining conditions underground.

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GLOSSARY OF TERMS

Anticline: A fold that is convex upward or had such an attitude at some stage of development.

Axis: A straight line, real or imaginary, passing through a body or system around which the parts are symmetrically arranged.

Bimodal: A frequency distribution characterized by two localized modes, each having a higher frequency of occurrence than other immediately adjacent individuals or classes.

Butt cleat: A short, poorly defined cleavage plane in a coalbed, usually oriented at right angles to the face cleat and sometimes terminating against it.

Buttress: A part of the rock near a fault along which no movement has occurred. The movement has taken place against this wall.

Clay vein: A body of clay, usually roughly tabular in form like an ore vein, which fills a crevice in a coal seam. It is believed to originate where pressure has been sufficient to force clay from the roof or floor into small fissures and in many cases to alter and enlarge them.

Coal cleat: A joint or system of joints along which the coal fractures. There are usually two cleat systems developed perpendicular to each other.

Draw slate: Soft shale that occurs above a coalbed and collapses after the removal of the coal.

Differential compaction: The relative change in thickness of mud and sand (or limestone) after burial due to reduction in pore space.

Dip: The angle at which a stratum or any planar feature is inclined from the horizontal. The dip is at a right angle to the strike.

Face cleat: A well-defined joint or cleavage plane in a coal seam. The major joint in a coal seam.

Fault: A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fence diagram: A diagram that is a drawing in perspective of three or more geologic sections with their relationship to one another (also called panel diagram).

Isopach map: A map that shows the varying of the interval (thickness) between two designated stratigraphic units or horizons; for example, a map prepared directly from two structure-contour maps by subtracting the elevations of the lower surface from those of the upper surface at each control point and drawing contours of equal interval between the two surface.

Joints: Fracture in rock, generally more or less vertical or transverse to bedding, along which no appreciable movement has occurred.

Linears: A straight or gently curved physiographic feature on the earth's surface.

Lithofacie map: A map that is based on lithologic attributes, showing variation in the overall lithologic character of a given stratigraphic unit. The map may emphasize the dominant, average, or specific lithologic aspect of the unit, and it gives information on the changing composition of the unit throughout its geographic extent.

Lithologic frequency map: A map that shows the number of rock types or the frequency of times that different rock types occur in a given vertical sequence over a given horizontal distance.

Monocline: Strata that dip for an indefinite or unknown length in one direction, and which do not apparently extend from sides of ascertained anticlines or synclines.

Orthogonal: A combining form meaning straight, at right angles.

Percent map: A map that depicts the relative amount (thickness) of a single rock type in a given stratigraphic unit as a percent of the total rocks in that vertical interval.

Rider coal: A thin unminable coal found closely above a thicker minable coalbed. Normally only a few inches thick.

Sandstone channel: A sandstone body that ranges in thickness from several inches to many feet and in length up to several miles and that cuts across structure and bedding of the enclosing rocks. Also called a clastic dike.

Shear fault: A fracture that results from stresses which tend to shear one part of a specimen past the adjacent part.

Slickenside: Polished and striated (scratched) surface that results from friction along a plane. The movement can be very slight.

Spalling of ribs: Relatively thin, commonly curved and sharp-edged, piece of rock (coal) produced by weathering.

Strike: The course or bearing of the outcrop of an inclined bed or structure on a level surface. It is perpendicular to the direction of the dip. (Also, the bearing of a horizontal trace on the bedding plane.)

Structure contour map: A map that portrays the subsurface configuration of structure of a unit by means of contour lines.

Syncline: A fold in rocks in which the strata dip inward from both sides toward the axis.

Synclinorium: A broad regional syncline on which are superimposed minor folds.

Thrust fault: A reverse fault that is characterized by a low angle of inclination with reference to a horizontal plane.

Washout: A channel cut into or through a coal seam at some time during or after the formation of the seam, and generally filled with sandstone.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975-603-752/4

INT.-BU.OF MINES,PGH.,PA. 20077

Report of Investigations 8093

Selected Geologic Factors Affecting Mining of the Pittsburgh Coalbed

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March 3 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Thomas S. Kleppe, Secretary
Jack W. Carlson, Assistant Secretary—Energy and Minerals
BUREAU OF MINES
Thomas V. Falkie, Director

This publication has been cataloged as follows:

McCulloch, Charles M

Selected geologic factors affecting mining of the Pittsburgh coalbed, by C. M. McCulloch [and others. Washington] U.S. Bureau of Mines [1975]

72 p. illus., tables. (U.S. Bureau of Mines. Report of investigations 8093)

Includes bibliography.

1. Coal mines and mining—Pennsylvania. 2. Coal mines and mining—West Virginia. 3. Methane. I. U.S. Bureau of Mines. II. Title. III. Title: Pittsburgh coalbed, Pennsylvania and West Virginia. (Series)

TN23.U7 no. 8093 622.06173

U.S. Dept. of the Int. Library

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SELECTED GEOLOGIC FACTORS AFFECTING MINING OF THE PITTSBURGH COALBED

by

C. M. McCulloch,[1] W. P. Diamond,[1] B. M. Bench,[1]
and Maurice Deul[2]

ABSTRACT

As part of the Bureau of Mines methane control program, the Pittsburgh coalbed was studied in Washington and Green Counties, Pa., and in Marion and Monongalia Counties, W. Va., where this coalbed is now being mined at its greatest depth. The coalbed thickness appeared to be structurally controlled; the bed was generally thinner near the axes of anticlines and thicker near the axes of synclines. The overburden isopach shows a similar relationship. Most of the clay veins in coal occur in the synclinal troughs, generally under sandstone roof.

Cleat orientations measured in 18 underground mines showed that face cleats are perpendicular to the axial trends of the folds, and the butt cleats are parallel to the axial trends, indicating structural control of the cleat.

Measurement and analysis of surface joint orientations provide a method for predicting the cleat orientations of the coalbed, but linears measured from infrared photographs and photoindex sheets helped only to determine regional trends.

The results of these investigations provide a geologic framework for rational planning for underground mine development to use the best available technology to cope with methane emissions, coalbed discontinuities, and related ground support problems.

INTRODUCTION

The Pittsburgh coalbed is one of the largest and most valuable mineral deposits in the world. It extends from the western tip of Maryland, west to Belmont County, Ohio, and from Allegheny County, Pa., southwest to Putnam County, W. Va. This report is focused on Washington and Greene Counties, Pa., and Monongalia and Marion Counties, W. Va., because this is the area of greatest active mining. Within this area (fig. 1) the coalbed crops out only

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[1] Geologist.
[2] Research supervisor.

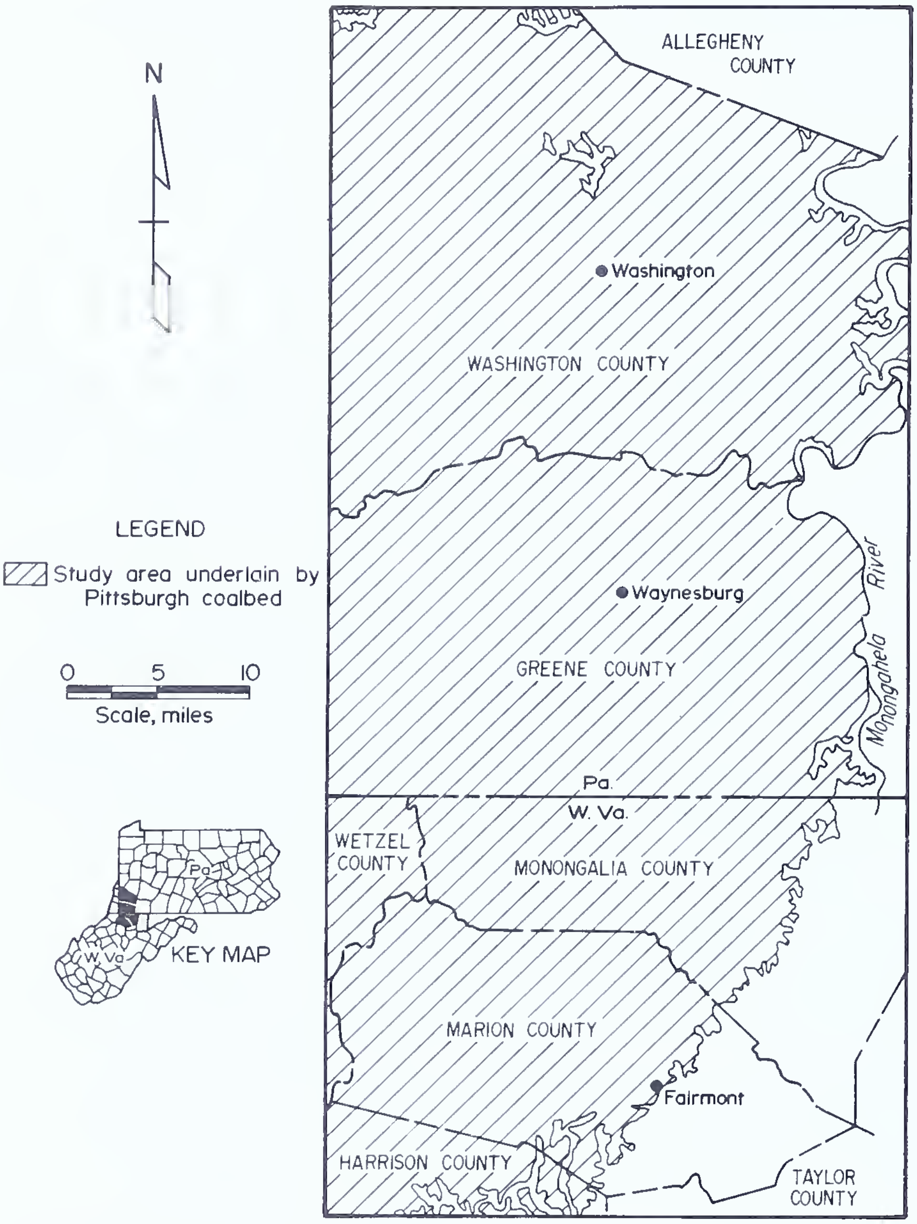

FIGURE 1. - Map of the study area and the portion underlain by the Pittsburgh coalbed.

in northern Washington County and along the Monongahela River, necessitating underground mining almost exclusively.

The Pittsburgh coalbed lies in an area known physiographically as the Allegheny Plateau and characterized by anticlines and synclines that normally dip less than 100 feet per mile. The strata above the Pittsburgh coalbed are composed predominantly of interbedded shales, sandstones, siltstones, and limestones with intermittent coalbeds. The critical vertical sequence above the coal is normally less than 50 feet.

In 1964, the U.S. Geological Survey (115)[3] determined from an extrapolation of data assembled by Latimer (71) that the Pittsburgh coalbed had yielded about 8 billion tons of coal from the beginning of mining in the early 1900's to January 1, 1965. This total was about 35 percent of the cumulative production of the Appalachian bituminous coal basin and 21 percent of the cumulative production of the United States. The coal reserves in western Washington and Greene Counties, Pa., and Marion and Monongalia Counties, W. Va., represent an important future source of coal. The coal here is deeper (up to 1,500 feet) than that previously mined in the Pittsburgh coal basin. Methane gas has been a continuing source of problems in the Pittsburgh coalbed, and such problems will probably increase with greater depth of mining. Roof instability and the occurrence of clay veins and sandstone channels are also possible.

This report deals with selected geologic factors that affect the mining of the Pittsburgh coalbed. Selected factors examined include structure, overburden, immediate roof strata, relation to joints and linears, and cleat orientations.

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[3] Underlined numbers in parentheses represent items in the bibliography preceding the appendixes.

Much of the Bureau of Mines methane control research has been conducted in the Pittsburgh coalbed (25, 64, 75). The present report gives results of one phase of this research, which is seeking to identify the geologic factors that influence methane accumulations and emissions in coalbeds and which may be used in planning the degasification and ventilation of coal mines and the recovery of mine gas. Similar studies can be conducted on other coalbeds.

ACKNOWLEDGMENTS

This project could not have been completed without the assistance of many people and companies. We thank Consolidation Coal Co., Bethlehem Mines Corp., Eastern Associated Coal Corp., and Jones & Laughlin Steel Corp., who provided personnel to escort us in our underground studies and supplied core logs, mine maps, and other necessary data.

We especially thank James Marshalek, supervisory mining inspector for the Mining Enforcement and Safety Administration (MESA); S. M. Linger, W. C. Doran, Jr., J. G. Tilton, and J. C. Patton of the Equitable Gas Co.; James Barlow of the West Virginia Economic and Geologic Survey; Herb Steinman of Jones & Laughlin Steel Corp.; and W. Edmonds of the Pennsylvania Geological Survey for supplying information and reviewing the manuscript.

The contributions of C. H. Elder and P. W. Jeran, Bureau geologists are acknowledged. They have spent considerable time on investigations of the Pittsburgh coalbed and were most helpful with suggestions and supplying data for the preparation of maps.

HISTORICAL BACKGROUND

The first investigation of the Pittsburgh coalbed dates back to 1759 when Kenny (52) referred to a coal being mined on the hills around Pittsburgh. Since that time, numerous investigations have resulted in more than 100 publications. See Bibliography.

Nineteenth century investigators were concerned primarily with the stratigraphy of the area and the problems in working out stratigraphic boundaries (72, 85, 98-100, 107, 115). Rogers (100) in 1884 was one of the first to realize the importance of the Pittsburgh coalbed in the mining industry.

The most comprehensive single work on the Pittsburgh coalbed is that published in 1954 by Cross (21), who studied the stratigraphy, petrology, origin, composition, and mining problems of the bed. Much of Cross' work is pertinent today, and his paper has served as a model for the present report.

As would be expected for so important a deposit, mapping has been extensive. The early 1900's saw a flurry of activity, with the Pittsburgh coalbed being mapped in parts of all four counties of the study area by Clapp (18), Munn (79), Hennen (45), and Hennen and Reger (46). The first detailed map showing the area underlain by the Pittsburgh coalbed in West Virginia, Ohio, and Pennsylvania was published by Burrough (16) in 1914 and was a fairly accurate map for the small amount of data available.

The coal-bearing Upper Pennsylvanian and Lower Permian rocks of the Washington, Pa., area have been studied by Berryhill, Schweinfurth, and Kent (11), who prepared a number of isopach and lithofacies maps of the area.

In 1972 Roen and Farrel (96) published a structure map drawn on the base of the Pittsburgh coalbed using published geologic maps of Pennsylvania, county reports from West Virginia and Pennsylvania, and coal company data. The 7-1/2-minute geologic quadrangles of Amity, California, Ellsworth, Hackett, Mather, Monongahela, Prosperity, Washington East, Washington West, and Waynesburg have been mapped by the U.S. Geological Survey. The Carmichaels, Oak Forest, and Midway quadrangles have been covered in other studies. Geological maps of the Blacksville, Fairmont East and West, Grant Town, Morgantown North, Osage, and Rivesville 7-1/2-minute quadrangles have been prepared by graduate students at West Virginia University.

The stratigraphy of the Monongahela Group in West Virginia, Ohio, and Pennsylvania has been studied by Hoover (47), who prepared a series of isopachs on all major units from the Redstone to the Pittsburgh coalbed. The Pittsburgh-Redstone coal interval in West Virginia has also been studied by Conti (20).

In preparation for the present report, underground geologic investigations were conducted in 18 mines operating in the Pittsburgh coalbed. Coal cleat orientations were measured, and the location and trend of sand channels and clay veins were obtained. Surface joints were measured to evaluate their relationship to cleat directions underground. An aerial photoanalysis was conducted to locate lineaments and evaluate their relationship to surface joints. Geologic factors influencing roof control were also investigated.

STRUCTURE AND STRATIGRAPHY OF THE PITTSBURGH COALBED

Regional Structure and Paleogeography

Most of the Pittsburgh coalbed lies in a broad, gently dipping basin. The basin is a highly dissected region of gently folded anticlines and synclines that decrease in intensity westward from the Allegheny structural front (fig. 2). The area is known physiographically as the Allegheny Plateau. The fold axes generally parallel the axes of the basin. The dip of the rocks is generally less than 1°. The forces that produced the folding and subsequent erosion exposed, or brought near the surface, numerous coalbeds that otherwise would still lie deeply buried.

Figure 2 is a structural contour map of the Pittsburgh coalbed by Roen and Farrel (96). The Bureau has drilled approximately 20 holes to the Pittsburgh coalbed within the study area, but the additional information obtained did little to alter the interpretation of the structural trends.

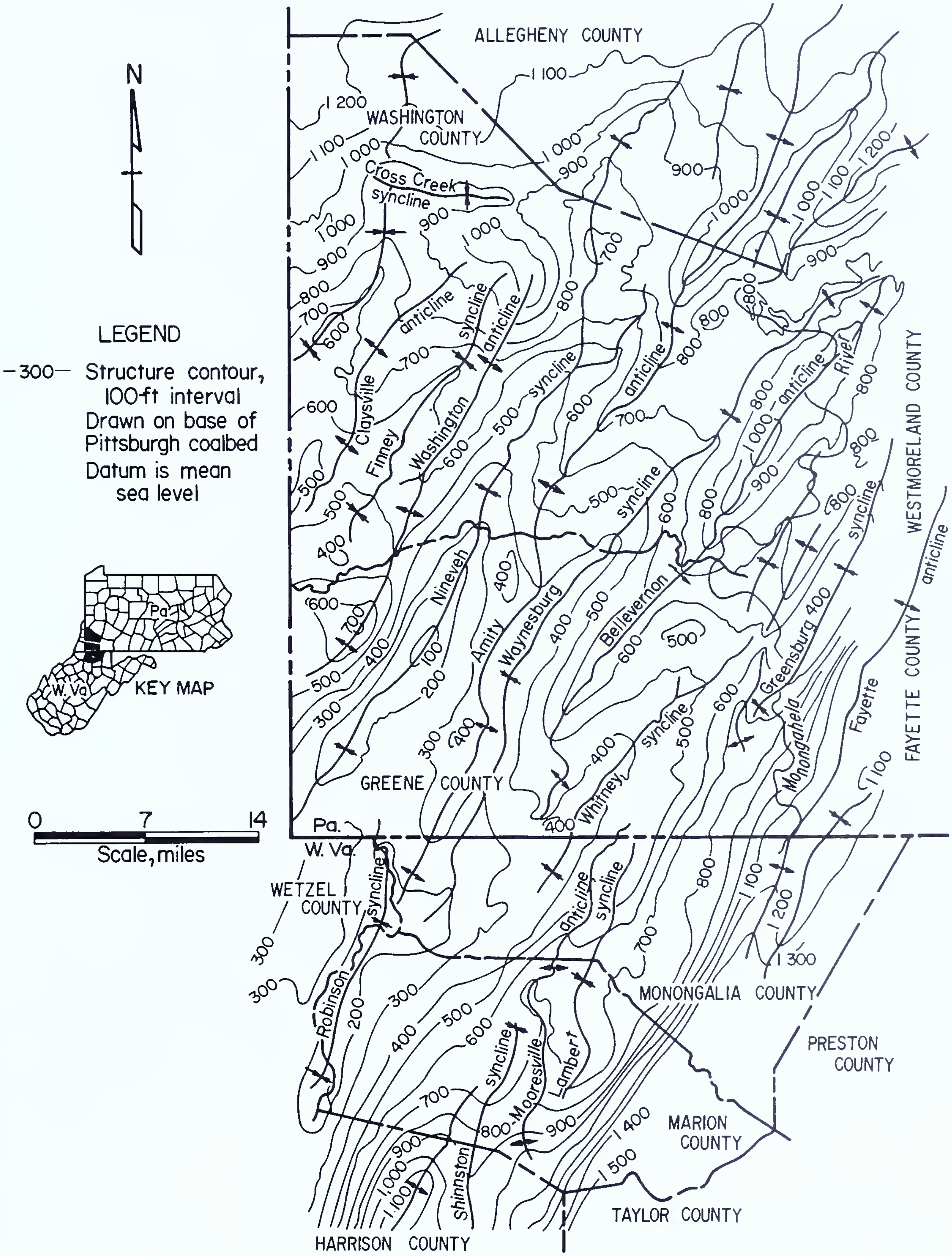

FIGURE 2. - Structure map drawn on the base of the Pittsburgh coalbed (97).

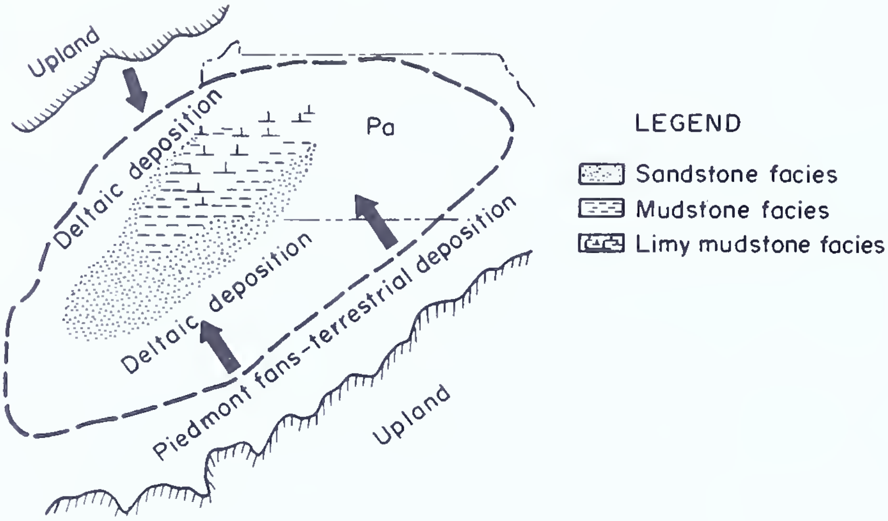

FIGURE 3. - Basin of deposition present in the study area during late Pennsylvanian time [taken from (12)].

The basin of deposition of the Pittsburgh coalbed during late Pennsylvanian time (fig. 3) occupied a large portion of Pennsylvania and adjacent areas of Ohio and West Virginia. The basin axis was defined by a bay which, according to Donaldson (26), expanded and contracted during Pennsylvanian time in response to the balance between tectonic subsidence, detrital supply, and eustatic changes in sea level.

Hoover (47) postulates a flood plain and interdistributary bay environment in the north and northwest part of the basin and a higher alluvial plain region along the south, southeast, and east side of the basin. Plant material, which eventually became the Pittsburgh coalbed, accumulated in a swamp environment associated with the deltaic sedimentation systems extending into the shallow bay. Darrah (23) notes that the climate of the area was probably moderate in temperature, rather than tropical as was once thought. Ferm and Cavaroc (32) and Conti (20) have made other paleogeographic investigations.

Thickness and Rate of Accumulation

A coal isopach (fig. 4) was prepared to give an idea of original minable coal in place. The interval measured included partings in the coal. It also included roof coal when not separated by more than 6 inches of shale or sandstone. It was constructed from more than 3,000 data points (fig. 5) derived from two sources, driller's logs of oil and gas wells and core logs from coal companies. The thickness data from the driller's logs, somewhat less reliable (probably ±2 feet) than those obtained from the detailed core descriptions, were mapped as reported. The reliability of the driller's logs depends in part on how long ago the wells were drilled, the type of equipment used, and the exactitude of the driller. Core data description generally correlated well with oil and gas well driller's logs. Mined-out areas are depicted on a separate map (fig. 6). Strip-mined areas, determined from the most recent topographic maps, are shown on the overburden isopach (fig. 7).[4]

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[4] Both the isopach of the coalbed and the overburden isopach are available from the authors'at scales of 1:24000 (one inch equals 2,000 feet). The isopach has a 100-foot contour interval on the 1:24000 maps. Also all other maps of the area are available on a scale of 1:96000.

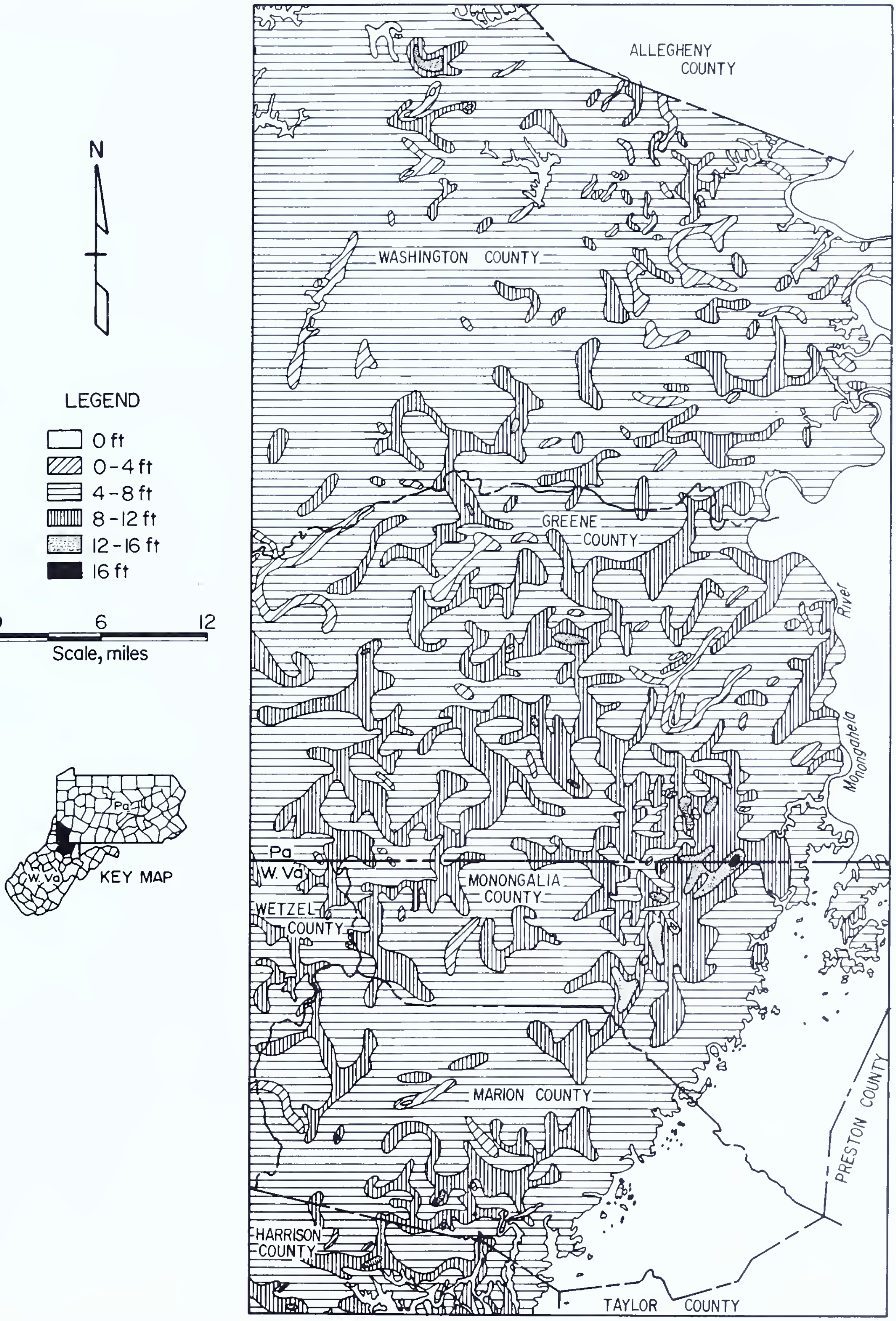

FIGURE 4. - Isopach of the Pittsburgh coalbed. (Sandstone cutouts are not included.)

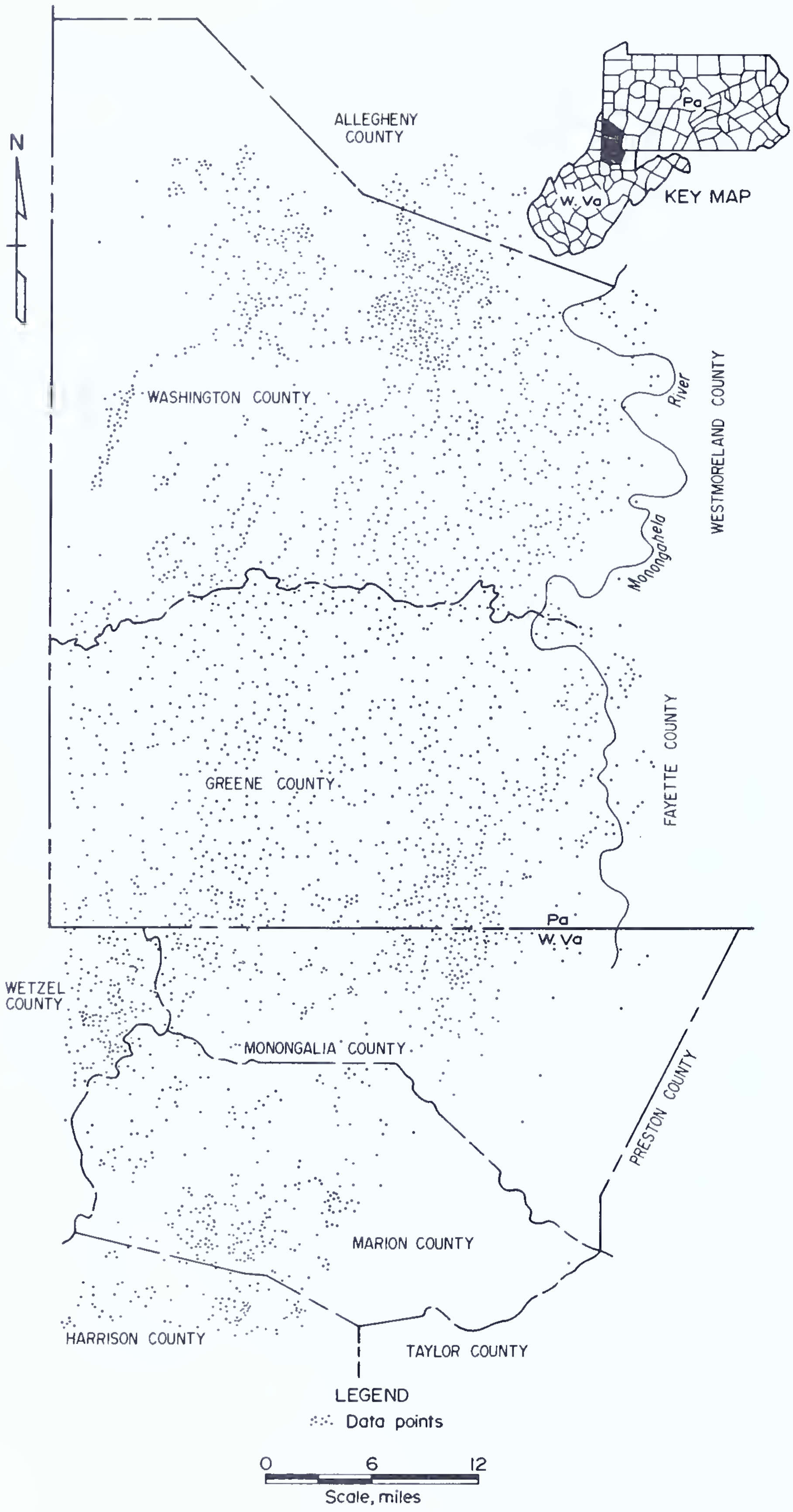

FIGURE 5. - Location of data points for the study area.

The areas of thicker coal (greater than 8 feet) do not directly overlie the regional synclinal troughs but are located generally on their flanks. It is suggested that the deposition of the Pittsburgh coal is in part structurally controlled, and that the axes of the principal structures have changed only slightly since deposition.

The dominant isopach trend (greater than 8 feet) coal begins in northern Harrison County, W. Va., runs through central Marion and Monongalia Counties, and extends into eastern Greene County, Pa. It is associated with the Shinnston and Greensburg synclines (fig. 2). Another trend, less distinct, about 10 miles to the west, begins in western Marion County, W. Va., and runs through central Greene County, Pa., into Washington County. This trend generally lies on the eastern flank of the Robinson and Waynesburg synclines. A third trend overlies the Nineveh syncline of western Greene and central Washington Counties, Pa.

The thickest coal measured was 16 feet in a core hole in northern Monongalia County, W. Va. (fig. 4), near the Pennsylvania border. Several thicknesses of 15 feet were also obtained from core descriptions in the same vicinity.

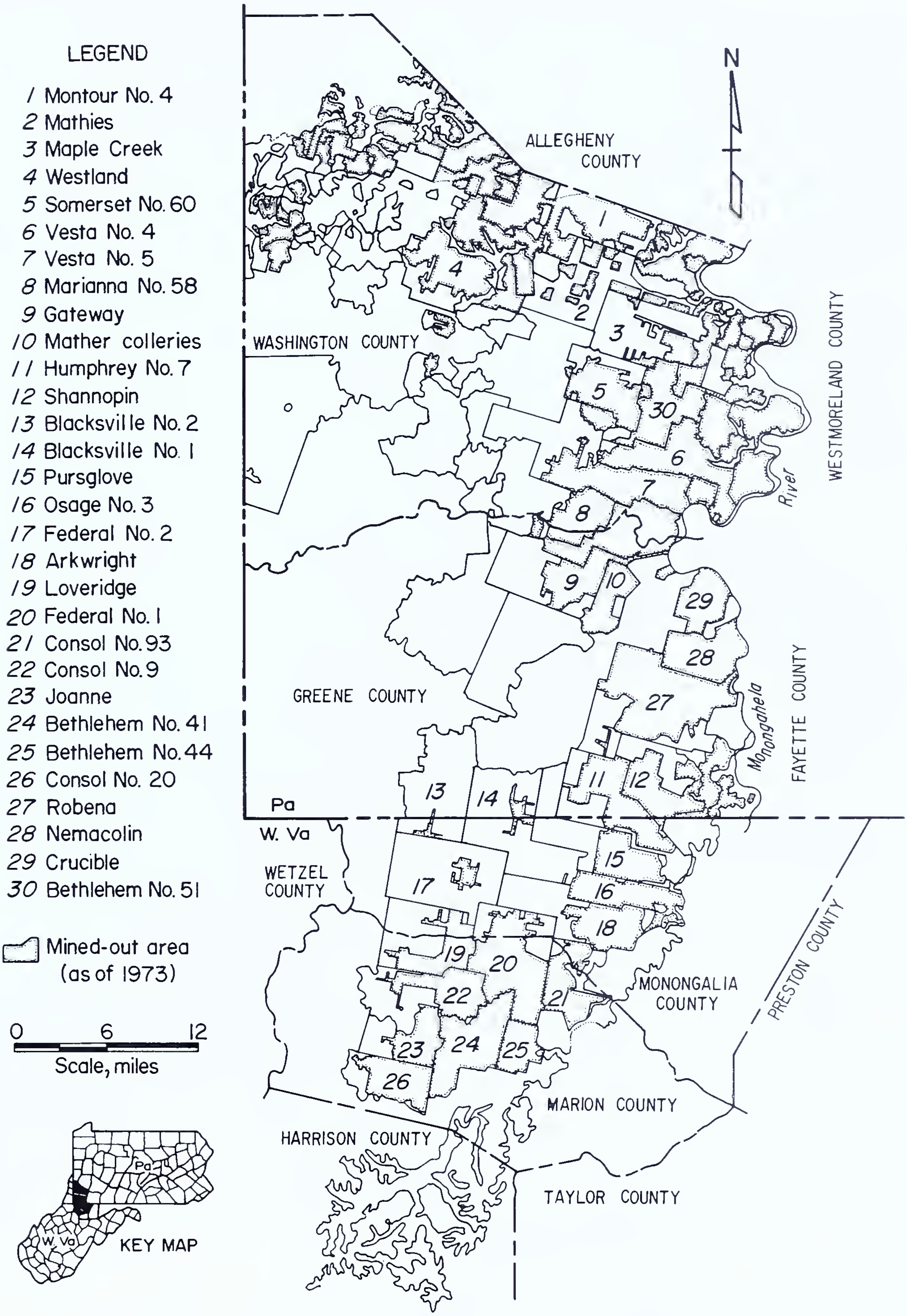

FIGURE 6. - Areas of the Pittsburgh coalbed that have been mined out.

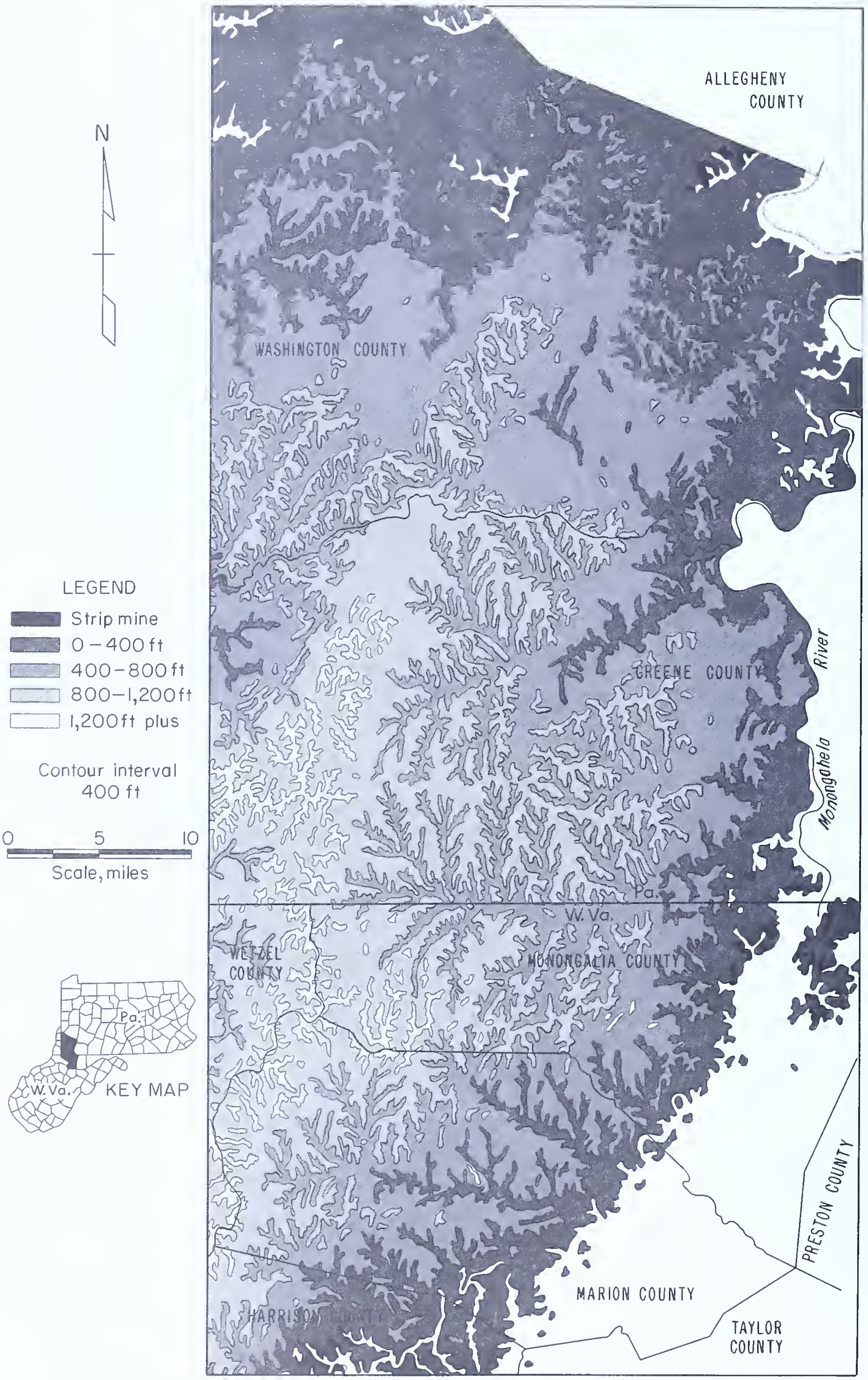

FIGURE 7. - Overburden isopach of the strata above the Pittsburgh coalbed.

Arkle (1) and Kent and Gomez (58) believe that the structures may have been "growing" during deposition, which could possibly explain the thinner coals near the axes of anticlines and the thicker coal deposits near the synclinal trough. Areas of low coal (less than 4 feet) are scattered throughout the area. Many have a preferred orientation, parallel to that of the regional structure. Some are closely associated with the anticlinal trends of the present structure. These thin areas may represent lower accumulation of plant material, greater erosion, or irregular surface of deposition. Several of the thin coal areas have a sinuous pattern suggestive of meandering streams and are probably the result of stream erosion.

Hoover (47) attributed the variations in thickness of the Pittsburgh coalbed to four possible causes: (1) Greater abundance of plant growth in some parts of the coalbed relative to others, (2) better preservation of accumulated plant debris in some areas, (3) influx of coarser detrital materials that may have diluted part of the peat already formed or terminated plant growth, and (4) the presence of deeper water, which prevented terrestrial vegetation from becoming established.

There were at least three other possible reasons for the variation in thickness: (1) Some parts of the swamp existed longer than others, (2) some areas may have been too high and dry to allow substantial plant growth, and (3) postdepositional erosion.

The time required for formation of the Pittsburgh coalbed can be estimated from the theoretical rate of accumulation for an ideal coalbed as determined by Ashley (3). Approximately 10 years would be required for 1 foot of peat to form from accumulated plant material. Since compaction and dewatering due to burial would reduce 1 foot of peat to 1-1/8 inches, approximately 100 years is required to produce 1 foot of compressed peat. The formation of 1 foot of coal requires between 3 and 3-1/2 feet of compressed peat, equivalent to at least 300 years. Thus, a 6-foot thickness of Pittsburgh coal would theoretically require 1,800 years of accumulation of plant material. This is only a reasonable estimate and cannot be considered a firm rule because the maximum thickness of 16 feet, which would require 4,800 years for deposition, is immediately adjacent to thinner coals. This maximum thickness may be due to greater accumulation of plant material in low areas as it was washed down from surrounding heights.

Generalized Stratigraphy of the Pittsburgh Formation

The Monongahela Formation in western Pennsylvania was raised to group rank by Berryhill and Swanson (12) who divided it into two formations, the Pittsburgh, which includes dominantly calcareous rocks with the Pittsburgh coalbed as its basal member and extends to the base of the Uniontown coalbed; and the Uniontown, which includes the Uniontown coalbed and the overlying predominantly sandy rocks to the base of the Waynesburg coalbed.

The Pittsburgh Formation (fig. 8) has five members: Lower, Redstone, Fishpot, Sewickley, and Upper. The Lower member includes the Pittsburgh coalbed at the base of the overlying Pittsburgh sandstone (when present). This sandstone is the thickest and most extensive sandstone in the Monongahela Group.

The Redstone member is typically siltstone and mudstone overlain by a relatively persistent limestone. Its basal member is the Redstone coalbed. The Fishpot member is composed mainly of siltstone and mudstone. The Sewickley member has the thickest limestone sequence, and the Sewickley coalbed is at its base. The Upper member has four limestone units and no underlying coals; its top is the base of the Uniontown coalbed. According to Hoover (47), the Monongahela Group includes the strata from the base of the Pittsburgh coalbed to the top of the Waynesburg coalbed. The thickness ranges from 220 to 450 feet and consists mainly of interbedded sandstone, siltstone, limestone, and shale with lesser amounts of coal and clay. In general, throughout the section the coals overlie the calcareous units but are separated from them by underclays. The Pittsburgh coalbed is the most extensive and economically important part of the Monongahela Group.

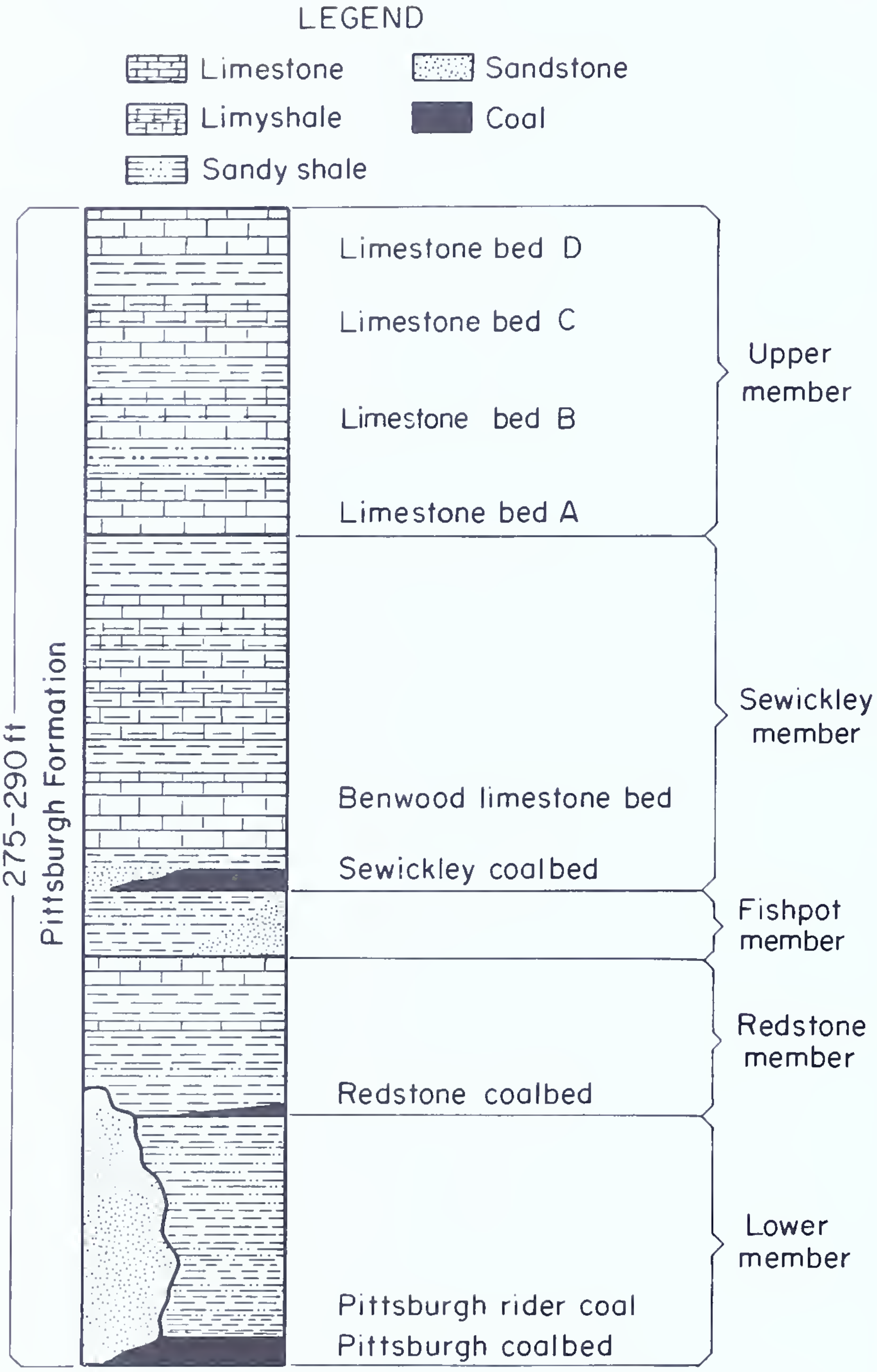

FIGURE 8. - Generalized stratigraphic column of the Pittsburgh Formation.

Overburden Thickness Above the Pittsburgh Coalbed

An isopach (fig. 7) was prepared to display the thickness of rock overlying the Pittsburgh coalbed in the study area. The map was constructed by subtracting the elevation of the structure, drawn on the base of the coal from the topographic elevation. Overburden thickness ranged from zero, where the Pittsburgh coalbed crops out, to more than 1,500 feet. Generally, the coal is shallow on the axes of anticlines and deeper in the troughs of synclines. The deepest cover in the study area is in southwestern Greene County and western

Monongalia and Marion Counties, where it averaged 1,200 feet with a maximum thickness of slightly over 1,500 feet.

As mining progresses under deeper cover, methane control and other mining problems will undoubtedly intensify. As gas emission rates are measured by the Bureau for increasing depths, attempted correlations with overburden thickness will be made to develop a theoretical model of depth versus gas emission for the Pittsburgh coalbed.

In Washington County the Pittsburgh coalbed crops out and is strip-mined in three localities (fig. 7). One outcrop in the western part of the county has no structural dependence. The other two occur on the axes of the Amity anticline and the top of the Westland dome. Maximum overburden thickness is slightly over 800 feet in the southwestern part of the county. Average thickness is approximately 400 feet.

In Greene County the coalbed crops out and is strip-mined along the Monongahela River. The overburden reaches a maximum thickness of 1,400 feet in southwestern Greene County and averages approximately 800 feet. The area where the overburden is relatively shallow is roughly parallel to the axes of anticlines, and the areas of the greatest overburden are in the synclinal troughs. For example, the Nineveh syncline in the southwestern part of the county has an overburden of between 800 and 1,200 feet. Along the Washington anticline to the west, the overburden ranges between 400 and 800 feet.

In Monongalia County there is stripping along the eastern edge of the Pittsburgh coalbed where it crops out. Of the four counties, Monongalia has the most extensive stripping of the Pittsburgh coalbed. The coalbed rapidly increases in depth to a maximum of 1,500 feet of overburden in the western part of the county.

In Marion County the Pittsburgh coalbed crops out along the eastern part of the county. The central part of the county has an average of 400 feet of overburden, whereas the western part has between 800 and 1,200 feet of cover.

Only small sections of Harrison and Wetzel Counties are covered in this study. In Wetzel County, the eastern part of which is included in this study, the overburden averages between 800 and 1,200 feet. In Harrison County, there is some outcrop and strip mining. The overburden averages approximately 400 feet with a high of 1,300 feet along the border between Harrison County and Marion and Wetzel Counties.

GEOLOGIC FACTORS CONTRIBUTING TO MINING PROBLEMS

Geological investigations can identify many underground mining problems. Sand channels that may intersect and cut out the coal can be located in advance of mining by analysis of core hole logs, and their probable course and influence on future mining operations can be predicted (76). Clay veins can be located and their trends can sometimes be established so that high gas concentrations, frequently associated with clay veins, can be anticipated.

A detailed map of the rock above the coalbed can be used to determine the length of bolts needed to anchor into competent strata for proper roof support. Such a map can also help to locate rock known to deteriorate rapidly when exposed to air so that resin bolts can be used.

Abnormal accumulations of water can be evaluated and perhaps related to fracturing of the roof rock or to a fault zone. These zones of weakness may also be responsible for high gas concentrations.

A detailed analysis of surface joints above a mine area can be prepared and examined for a possible relationship to the coal cleat directions and roof joints. Local deviations in joint and cleat directions serve as a basis for modifying mine projections. The cleat and joint analyses also supply information related to roof stability. For example, excessive spalling of ribs when mining parallel to cleat directions can sometimes be corrected by rotating the direction of mining 45°.

Strata Above the Pittsburgh Coalbed

The strata overlying the Pittsburgh coalbed vary locally and regionally as shown in the fence diagram (fig. 9). This figure was prepared using 77 core logs, electric logs, and other data selected from more than 500 logs to best represent the regional stratigraphic trends. The most common rock type directly overlying the Pittsburgh coalbed is the "draw slate" or "roof slate" (miners' terminology), consisting of alternating thinly bedded, dark gray to black, fissile carbonaceous shale, coal stringers, and sandstone lenses. This draw slate unit is generally less than 4 feet thick, but thicknesses up to 12 feet have been observed.

In the central part of the study area, the most common rock types above the draw slate are limestone and calcareous and silty shales. Surrounding the central area is a sequence of shales and massive sands. Other areas of massive sand development are shown on the sandstone channel map (fig. 10).

In Monongalia and Marion Counties, W. Va., the rocks above the coal and draw slate are predominantly limestone and shale, although the "limestone" of older core logs is more likely interbedded limestone, shale, and siltstone; in earlier years these rock types were not usually differentiated. The only sand deposits in these two counties are along the eastern margin of the area.

The roof rock in Greene County, Pa., is similar to that in Monongalia and Marion Counties, W. Va. Limestone is still dominant in the south but decreases in importance toward the northern border where large sand bodies become more prominent. The Pittsburgh sandstone unit may be up to 80 feet thick.

In Washington County, Pa., limestone dominates the southwestern portion, sandstone the southern and central area, and shale the northern portion. Throughout the area, a few coals are detected, but there appears to be no pattern to their occurrence.

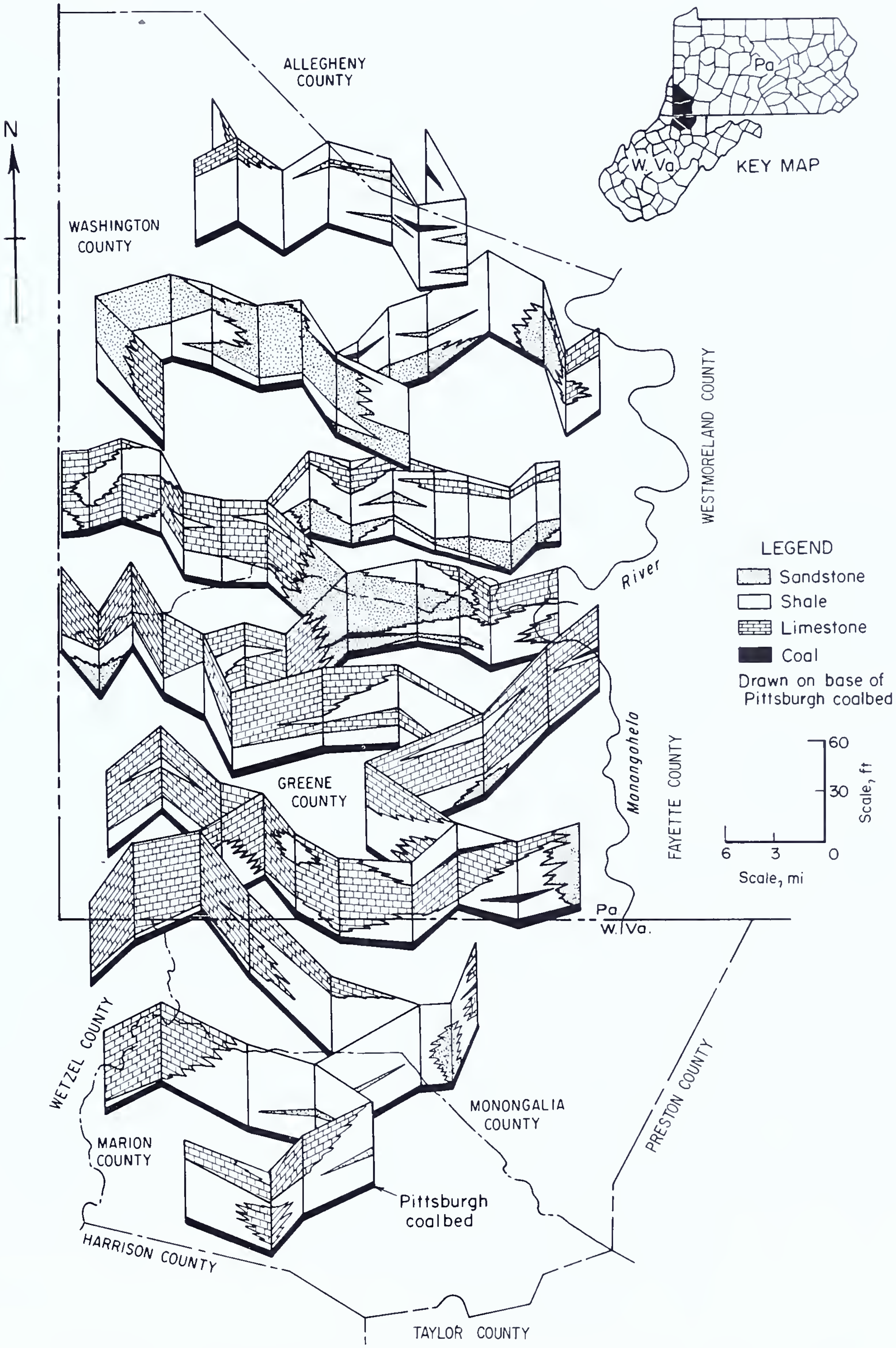

FIGURE 9. - Fence diagram of the strata directly above the Pittsburgh coalbed for the study area.

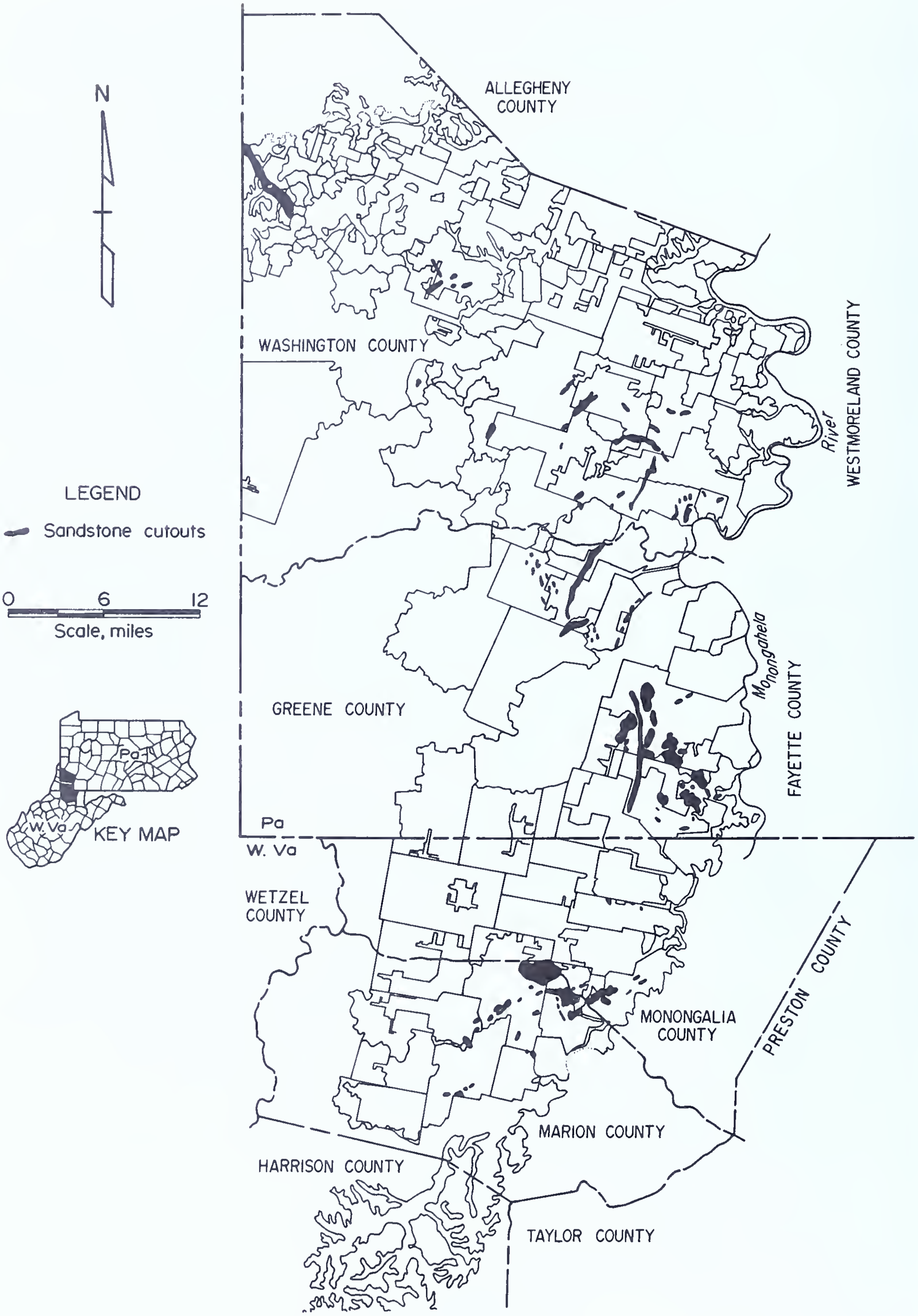

FIGURE 10. - Map of the known sandstone channels cutting into the Pittsburgh coalbed.

An isopach of the Pittsburgh sandstone prepared by Hoover (47) covers the known extent of the Pittsburgh sandstone in Monongalia and Marion Counties, W. Va., Greene County, Pa., and part of Washington County, Pa. (fig. 11). The sandstone bodies trend predominantly either to the northeast or northwest. The thin portions of the sandstone especially seem to be oriented to the northeast, as are the axes of the folds, which again suggests some structural control. There is also the possibility that the sandstone bodies are sedimentologically controlled, as suggested by W. Edmonds of the Pennsylvania Geological Survey (personal communication, available for consultation at Bureau of Mines Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.). The northeast-oriented bodies could be related to the strike of the strandline and could have formed as longshore bars. The northwest-oriented bodies could be down-paleoslope features such as alluvial valleys. A correlation may also exist between the thickness of the sandstone and areas of sandstone cutouts in the coal.

Sandstone Channels

Sandstone channels are lenticular, sometimes sinuous bodies of sandstone extending into, and sometimes completly through, a coalbed. Figure 10 is a map of known sandstone channels in the Pittsburgh coalbed, encountered in underground mining operations. Cross (21) also reports a channel extending from southwestern Pennsylvania to Monongalia County, W. Va., generally paralleling the Monongahela River. The channel then turns westward at the Monongalia-Marion County border.

Most of the known channels are within the present mine workings. Channels are difficult to detect in advance of mining because exploratory drilling of a mine property is frequently on 1-mile centers or more, whereas the channels are usually less than 2,000 feet wide. A much closer spacing, preferably 2,000 or 3,000 feet, will enable more detailed mapping and predicting of sandstone channel trends in advance of mining.

Even when a sandstone channel is not directly encountered in the core drilling, other evidence may suggest the proximity of one. The coal may become abnormally thick, sometimes even doubling in thickness near a sandstone channel by possibly washing to the side or by differential compaction. The sulfur content may increase toward channel areas. Channels can also possibly be detected by analysis of the related sediments using sedimentological and paleodepositional techniques, but this would be beyond the scope of this paper. Donaldson and Morton (27) listed five criteria that may be helpful in predicting channels: (1) Presence of clay veins, (2) change in coal type, (3) increase in the number and thickness of partings, (4) increase in detritals in the coal, and (5) a down-bowed parting.

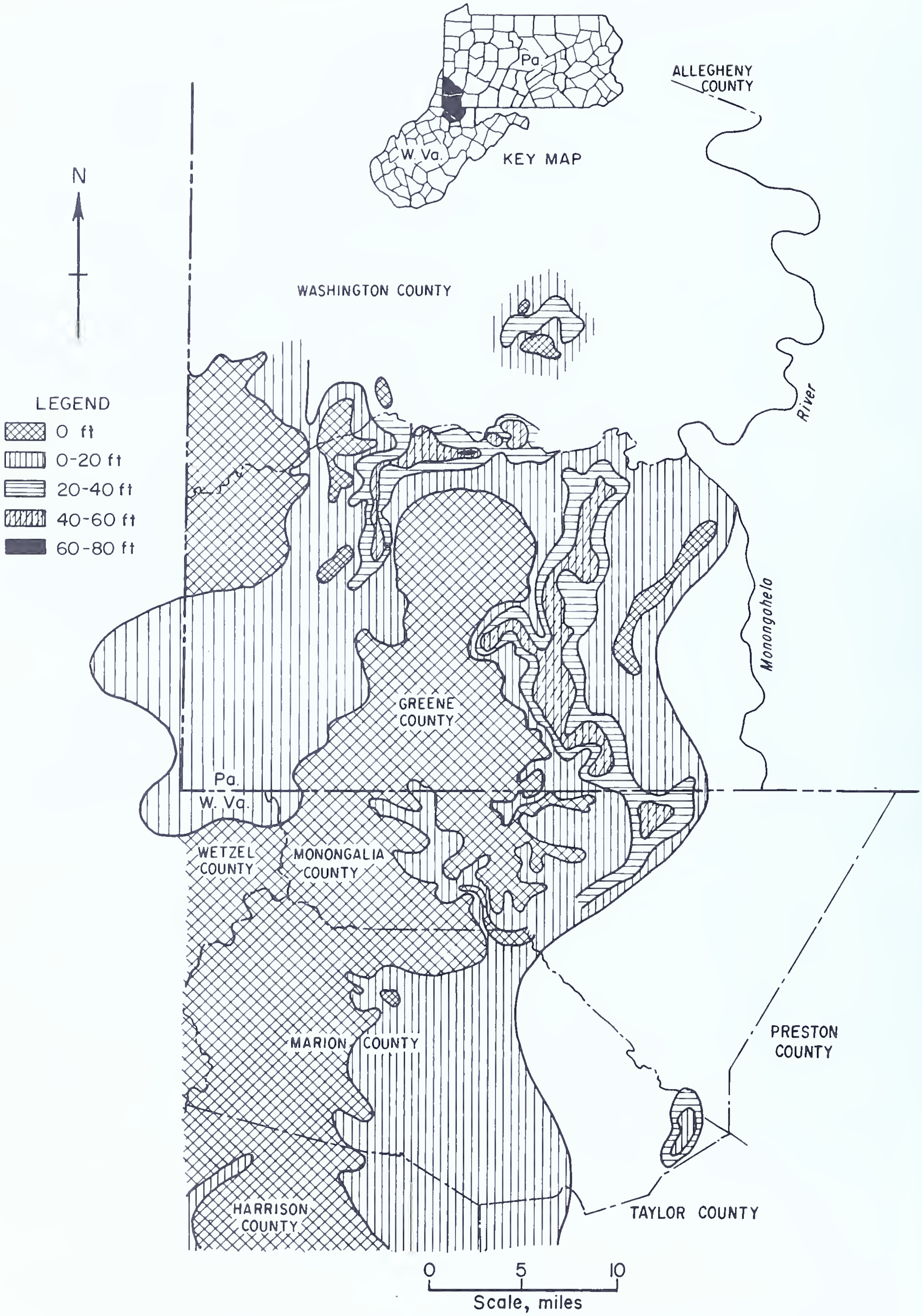

FIGURE 11. - Isopach of the Pittsburgh sandstone (48).

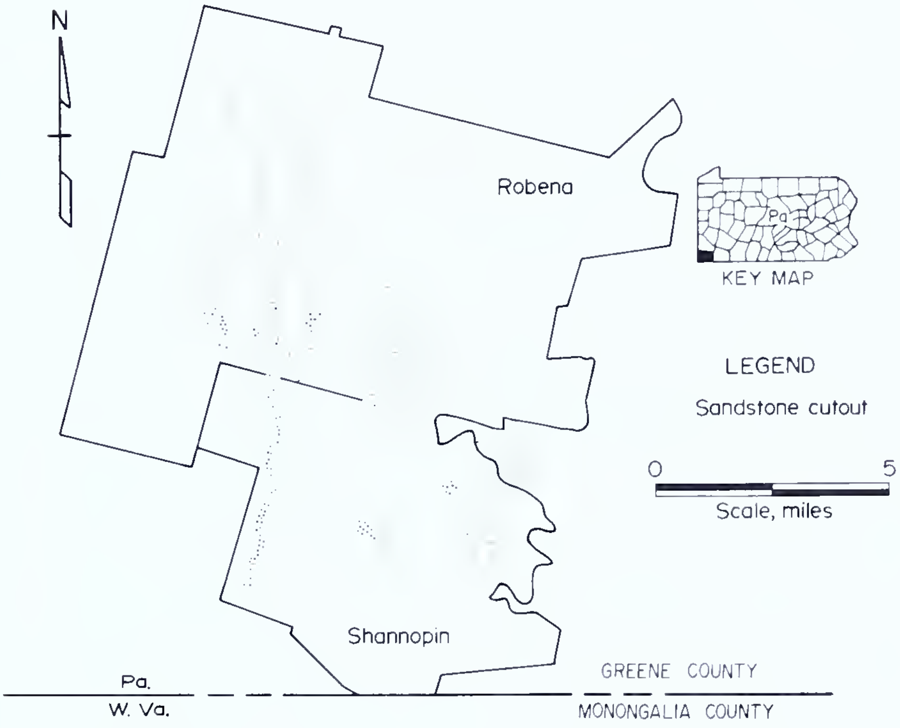

FIGURE 12. - Map of the Shannopin and Robena mines with sandstone cutouts.

At the Shannopin and Robena mines in Greene County, a number of channels intersect the coalbed (fig. 12). A fence diagram (fig. 13) of the area around the Shannopin mine shows a large lenticular sandstone body (Pittsburgh sandstone) overlying the coal. When the location of the sandstone channels that intersect the Shannopin and Robena mines are plotted on figure 11, these washouts are seen to occur in an area where the sandstone is 40 to 60 feet thick. Bureau geologists have found that when core logs indicate that such a sandstone body is approaching the coal, the coalbed is very likely to be cut out. Where the strata for approximately 40 feet above the Pittsburgh coalbed consist of limestone and shale, there is little chance of encountering a sandstone channel during mining. Figure 10 also shows other mines where sandstone channels have occurred.

Clay Veins

Clay veins are wedges of indurated clays and silts that penetrate the coalbed from either above or below. They can be vertical (parallel to the cleat directions) or form an angle of about 45° with the vertical (parallel to shear directions) (fig. 14).

Clay veins encountered in mines are usually crooked, are frequently angular, and interfinger with the coal rather than forming smooth contact surfaces. They may be hard enough to damage mining equipment. Thickness normally ranges from 1 inch to several feet but may be up to 15 feet. A total length of more than 1,000 feet has been observed underground.

There are two physical types of clay veins. The first occurs as inclusions within a clay-silt matrix and has a conglomeratic or brecciated appearance. The second type is composed of small interlocking lenslike masses of shale fragments with convoluted, slickensided surfaces.

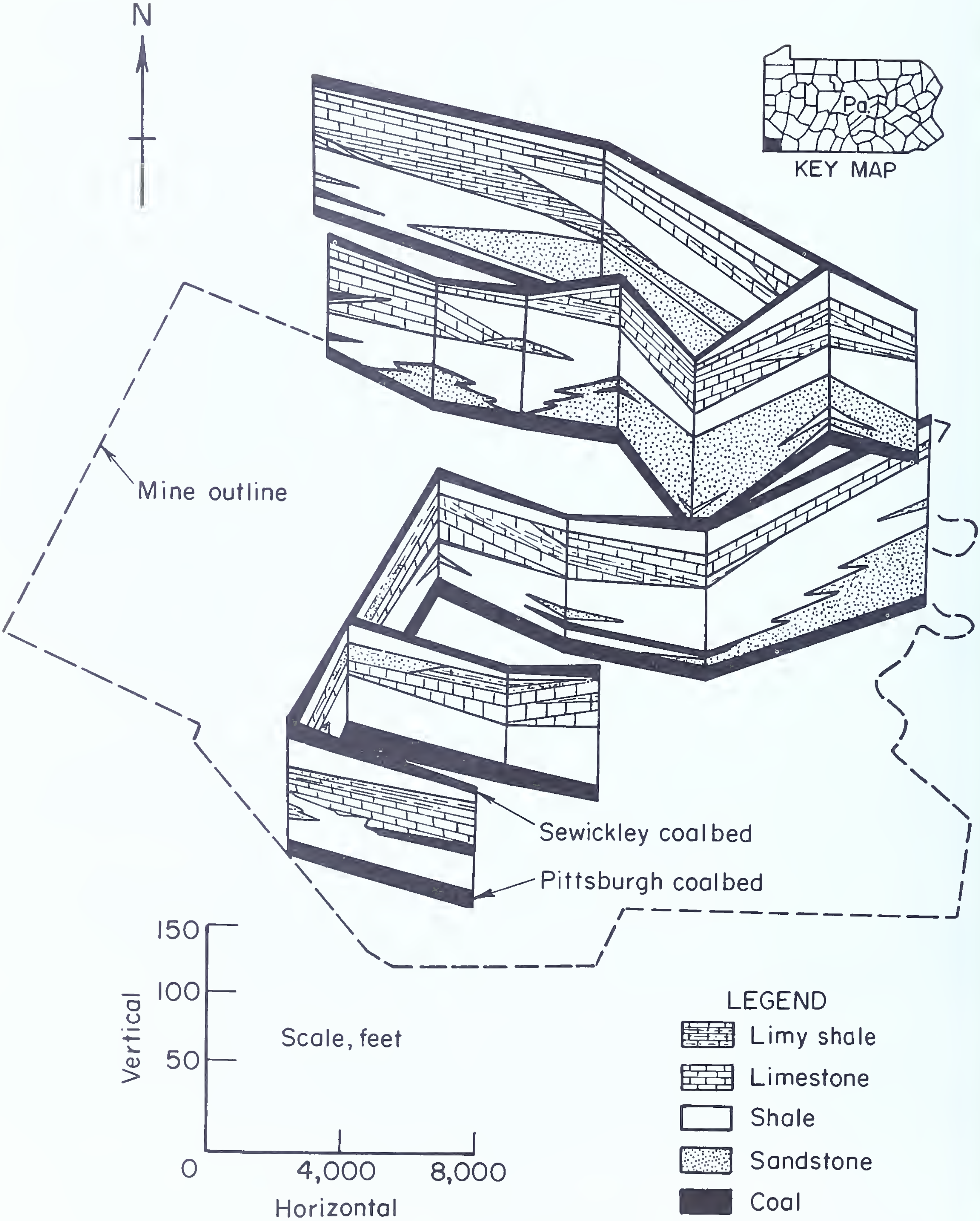

FIGURE 13. - Fence diagram of the strata above the Pittsburgh coalbed at the Shannopin mine.

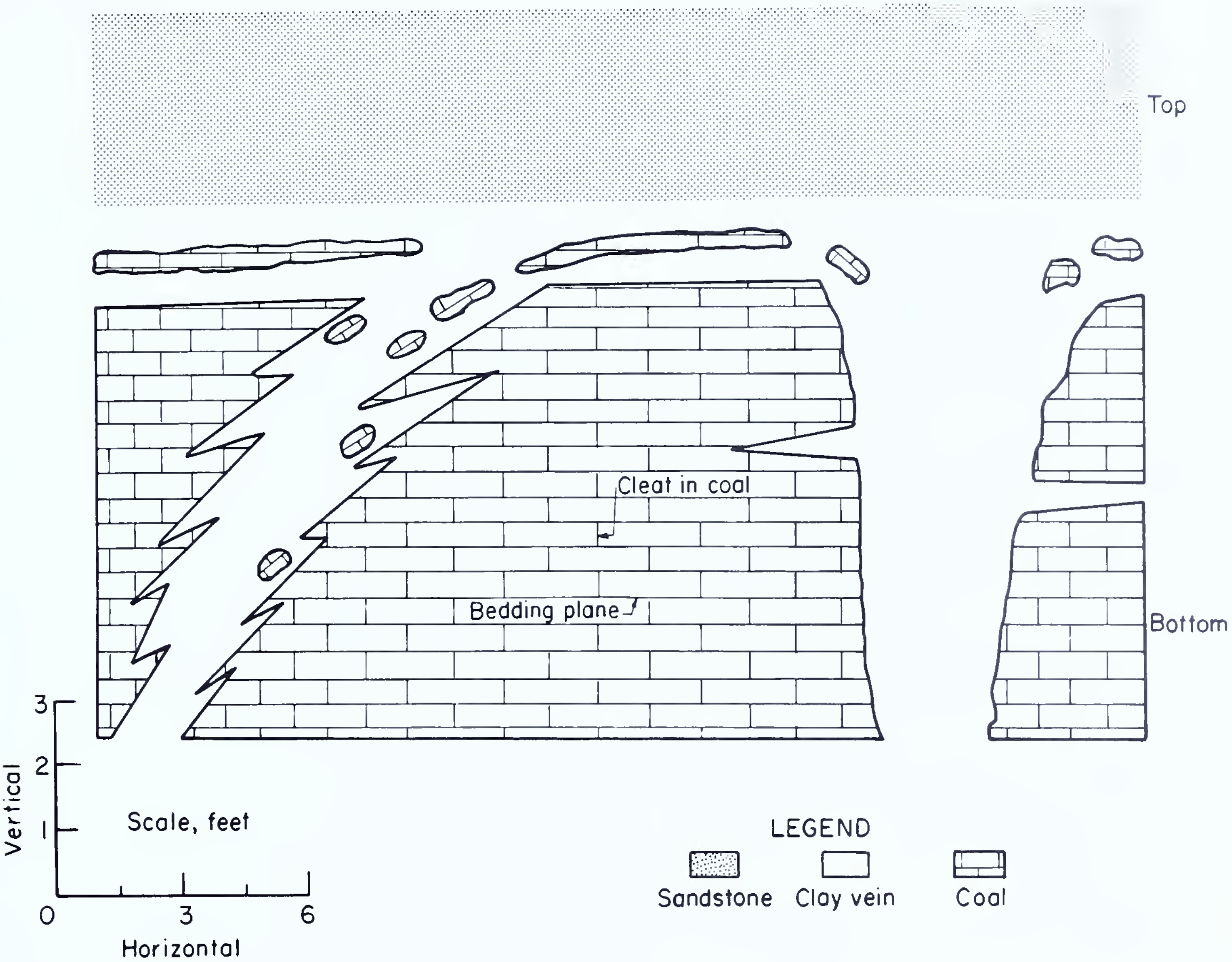

FIGURE 14. - Generalized cross section of clay veins intersecting coalbeds.

Clay veins were found in the following mines operating in the Pittsburgh coalbed (fig. 15): Mathies, Bethlehem Nos. 41 and 44, Marianna No. 58, Gateway, Shannopin, and Vesta No. 5; all these mines have a predominance of sandstone in the immediate roof. Two other adjacent mines, Loveridge and Federal No. 2, show no clay veins, and their roof strata are predominantly shale and limestone.

The presence of clay veins can greatly affect mining conditions. They often form cells within which large volumes of gas are isolated under high pressure. A test hole drilled into a cell enclosed by such a clay vein measured a confined pressure of 263 lb/in^2 (41). The gas flow from a 2-inch hole drilled horizontally into the coalbed through the clay vein at this point produced an average of 78,000 ft^3/d of gas for a short time. When mining encounters such a cell, large volumes of gas are released rapidly into the mine creating an explosion hazard. Also the chance of an explosion is increased by the sparks that are generated when mining into clay veins with both continuous miners and lognwall systems.

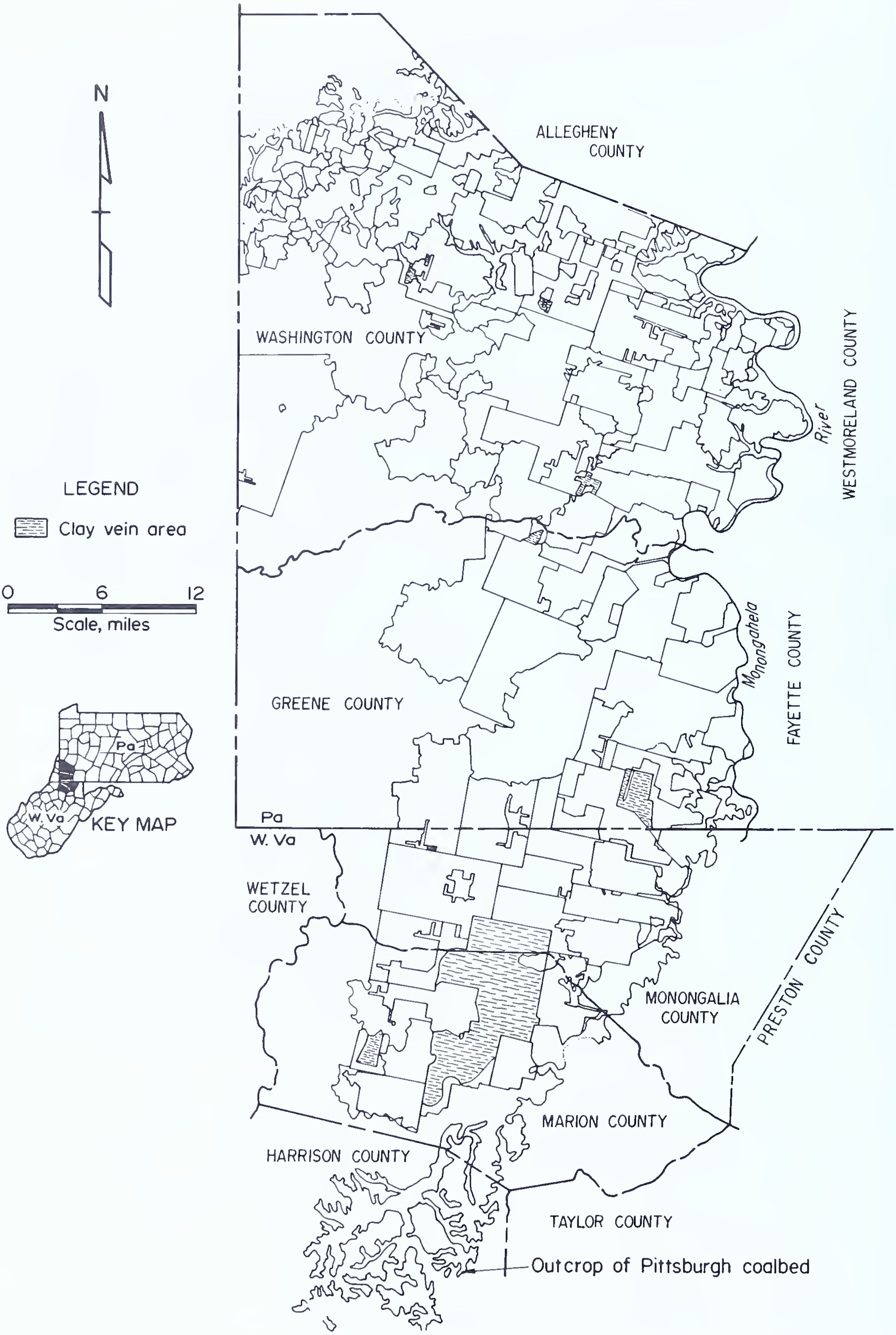

FIGURE 15. - Mines operating in the Pittsburgh coalbed with abundant clay veins.

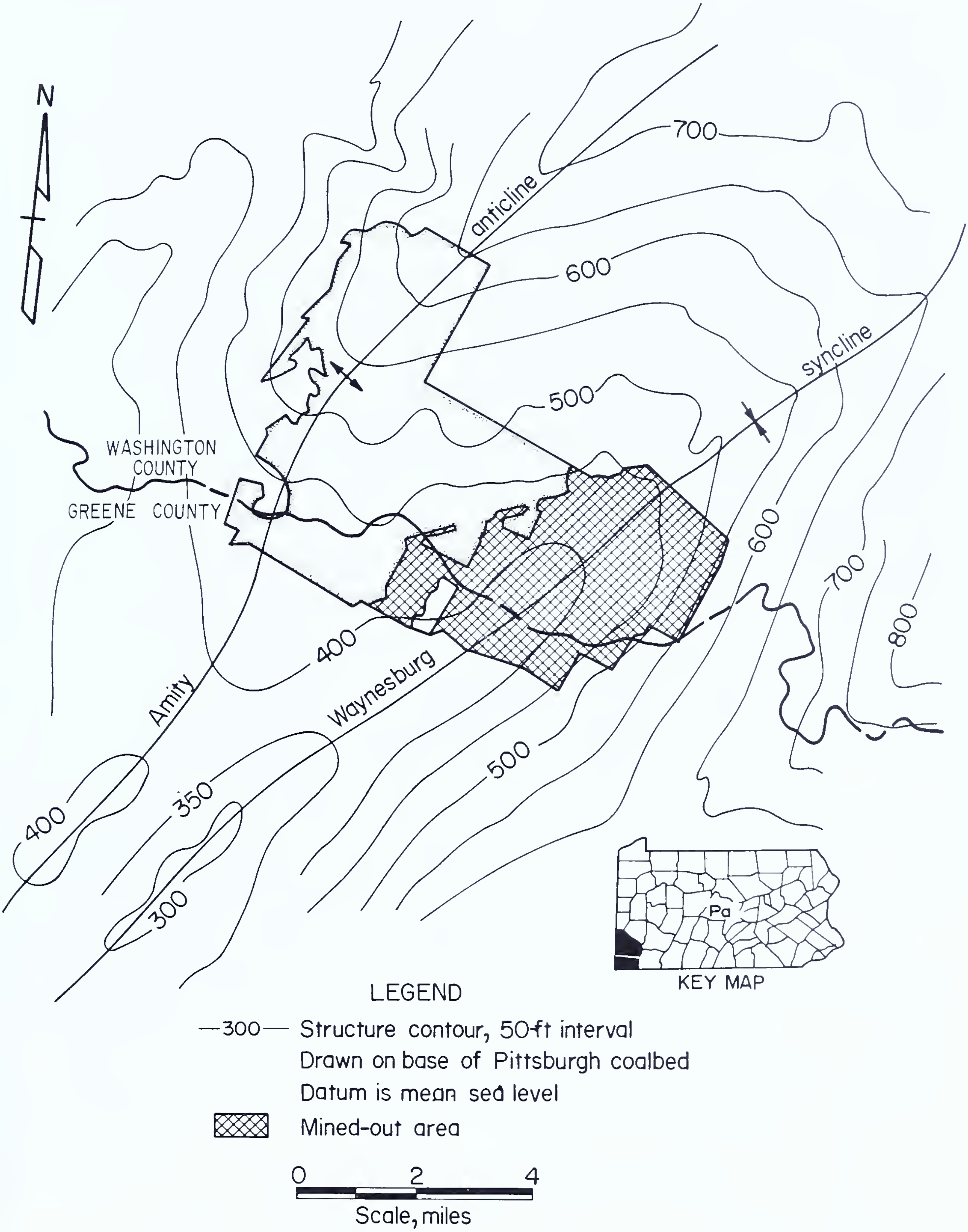

FIGURE 16. - Location and structure around the Marianna No. 58 mine.

Clay veins generally extend into strata immediately overlying the coalbed, sometimes for as much as 10 feet vertically. This breaks up the lateral continuity of the layered roof strata, causing roof instability. Roof failures tend to be more frequent when clay veins are almost parallel to the entry than when they are at right angles. Mining of clay veins also produces a marked increase in the percentage of rejects in the coal preparation plant.

The Marianna No. 58 mine is an example of a mine with clay vein occurrences. It is located in the trough of the Waynesburg syncline (fig. 16). The greatest frequency of clay veins occurred in a section of the mine located within the synclinal trough (fig. 17). The clay veins formed cells with sides oriented subparallel and subperpendicular to the axial trend of the trough.

Clay samples from the Marianna No. 58 mine were analyzed by X-ray diffraction to determine their mineralogical composition. Comparison of mineral compositions showed a near-perfect match between clay veins (fig. 18A) and the draw slate or roof rocks (fig. 18B) above. The major mineral peaks (quartz, kaolinite, and illite) all matched in intensity and slope. The floor rock samples (fig. 18C) showed a different composition, with calcite and quartz predominating, indicating that in this case the clay vein was injected from the roof rock, not from the floor rock. In some cases, clay veins are injected from underclays or shale lying below the coalbed up into it. Examples occur in the Redstone coalbed and in several coalbeds in western Kentucky.

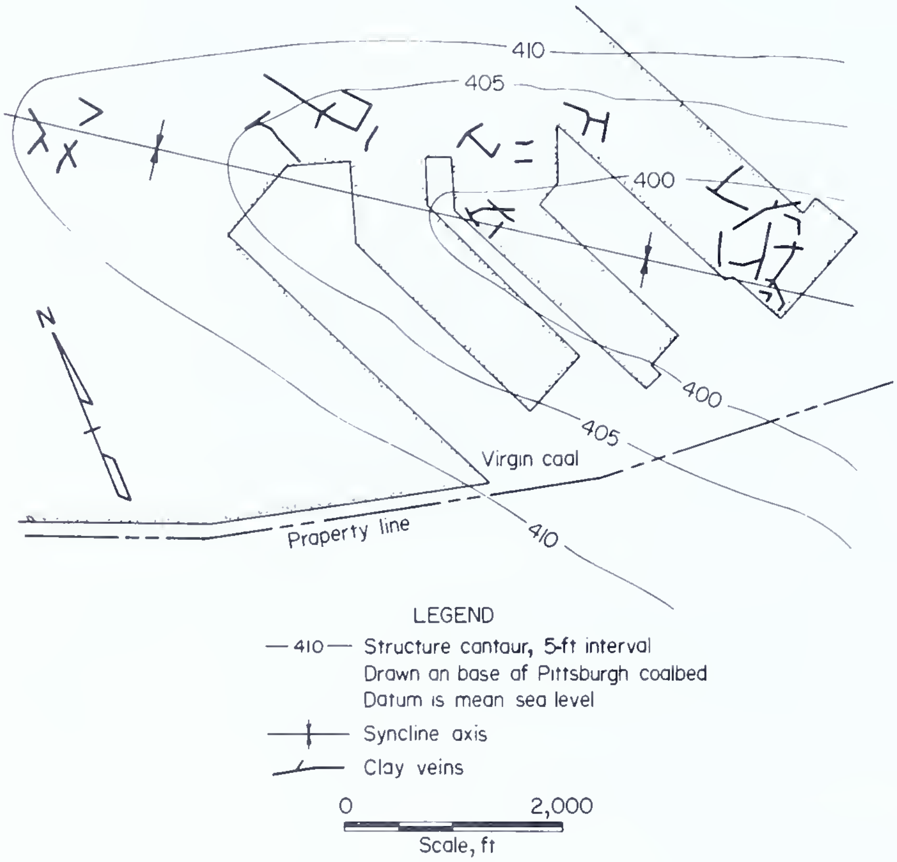

FIGURE 17. - Clay veins in synclinal trough at the Marianna No. 58 mine.

Based on Bureau research, it has been postulated that the clay veins intruded the coal after coalification had taken place. This conclusion is supported by the presence of coal fragments with good cleat development in clay veins. As the coal fragments were layered and the layers were parallel to the dip of the clay vein (fig. 14), it would appear that clay was not injected into cracks in peat as suggested by Raistrich and Marshall (90), but was forced into the coalbed after coalification.

It appears that the clay veins in the Pittsburgh coal bed are probably the result of tectonism, as in the Marianna No. 58 and

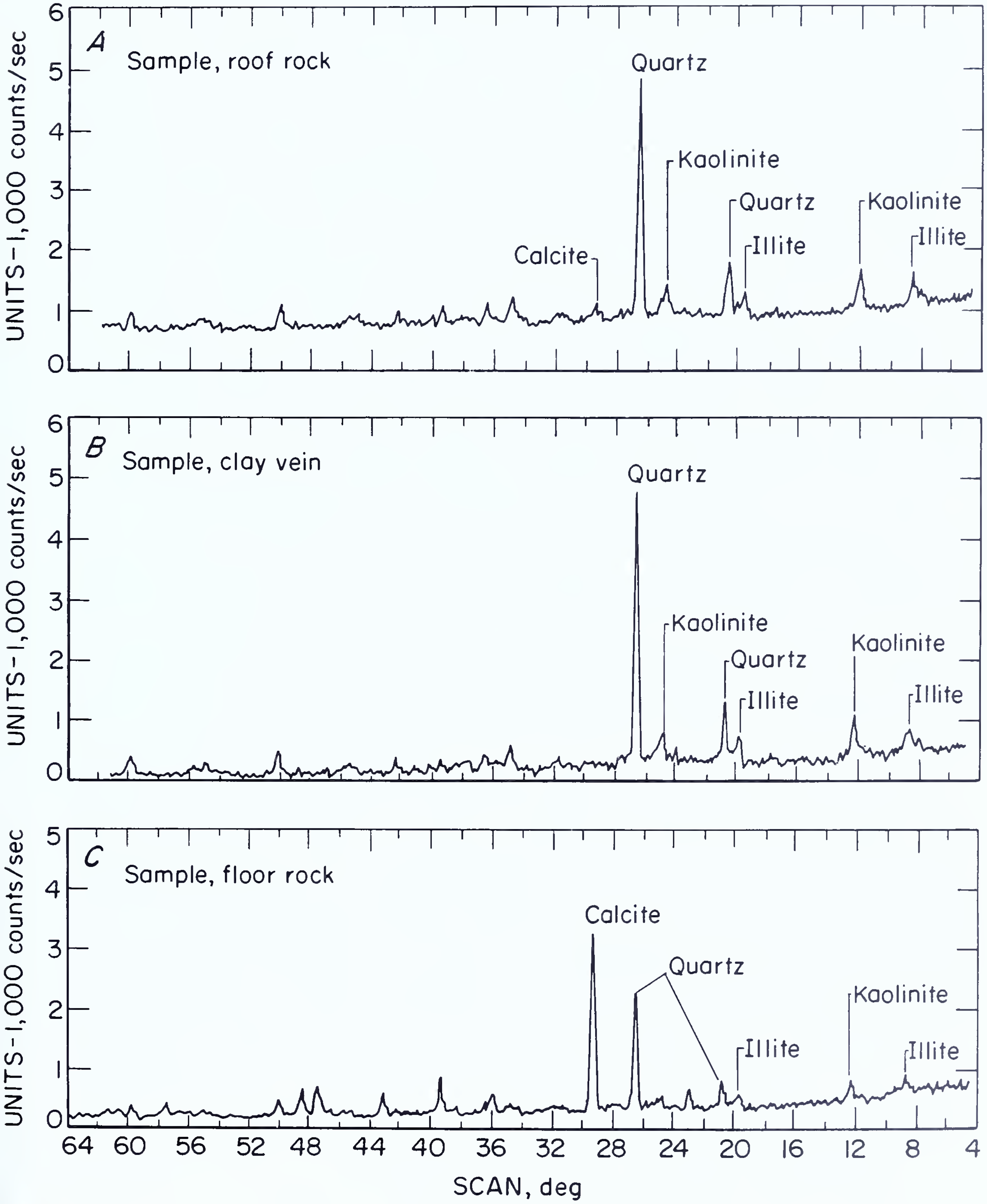

FIGURE 18. - X-ray diffraction charts of (*A*) the clay vein, (*B*) the roof rock, and (*C*) the floor rock lithologies.

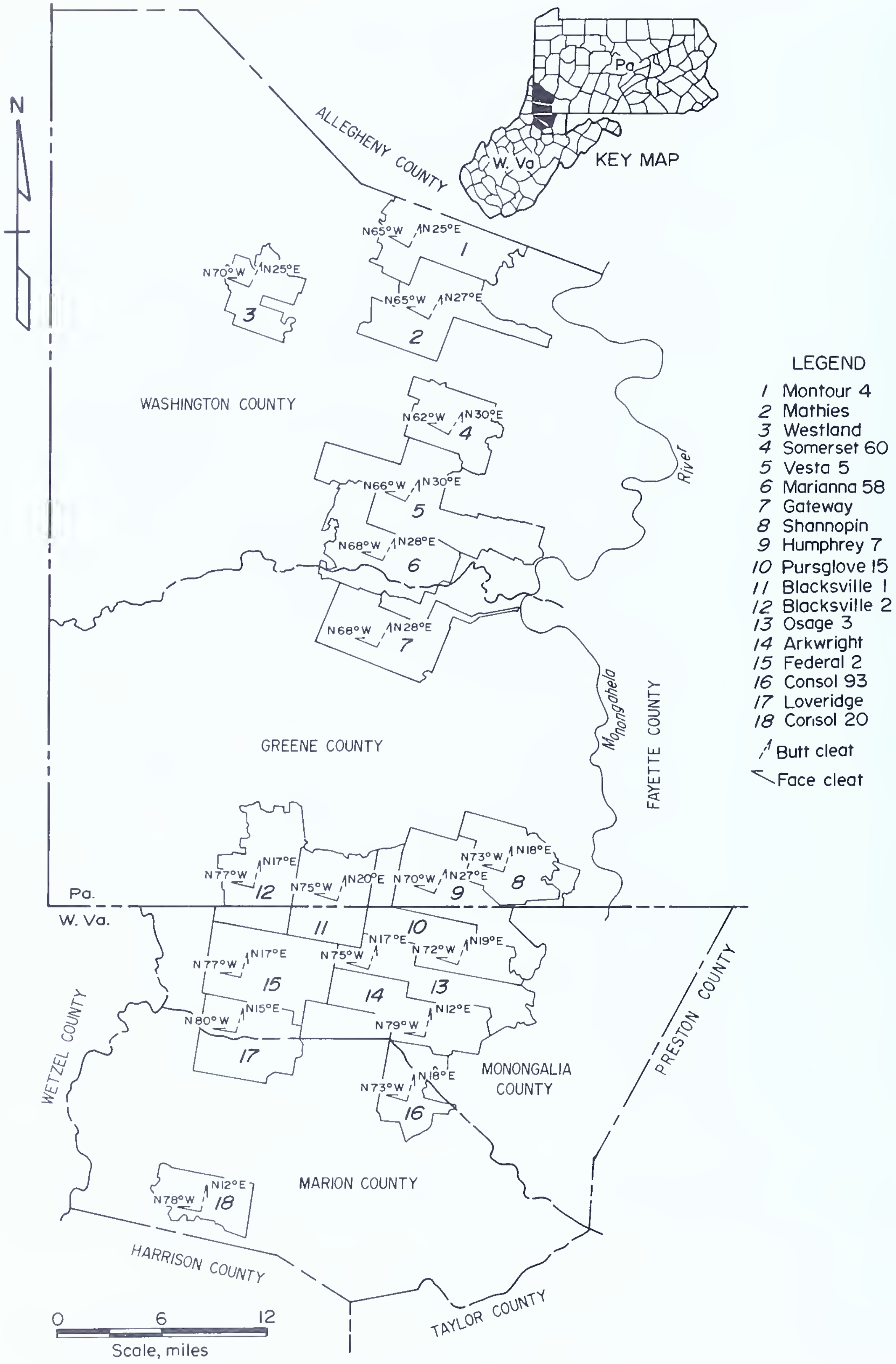

FIGURE 19. - Cleat systems in mines operating in the Pittsburgh coalbed.

Shannopin mines, although they may also be related to differential compaction in a depositional environment such as described by Wilson (124) in the central Missouri coals. This would explain the thick sandstone units found above them, whereas mines with limestone and shale roofs have no clay veins. The only known evidence of igneous activity within the study area is a peridotite dike found in Fayette and Greene Counties, Pa. The dike has been noted by Cross and others, and its presence has been confirmed by exposure in mine workings. The dike, which has been traced on the surface for approximately 15 miles, ranges in width from a few inches to several feet and tends to be perpendicular to the axial folds. The coal around the dike has been naturally "coked."

Cleat Within Mines

Cleat is the natural vertical fracture system in bituminous coalbeds. It is usually composed of a fundamental system of two components (sets) at 90° to each other. The more dominant fracture plane is the face cleat; the minor fracture plane is the butt cleat. The face cleat is more continuous, crossing bedding planes in the coal and extending for many feet, and tends to be perpendicular to the fold axes. The butt cleat is short, is often curved, and is a discontinuous feature that frequently terminates against the face cleat.

In the past, the orientation of the cleat in the Pittsburgh coalbed controlled the direction of mining. As coal tends to break along the cleats, it was easier to mine parallel to the cleat than at an angle to it. This has changed with the introduction of continuous miners, which mine as fast at an angle to the cleat as parallel to it. However, cleat is still very important because its orientation determines directional permeability which, in turn, determines the flow of methane and water into the mine workings (64, 75). When mining advances perpendicular to the face cleats, much more gas and water are emitted into mine workings than when the advance is parallel to the face cleat.

Determination and Analysis of Cleat Orientation

Cleat surveys were conducted in 18 mines operating in the Pittsburgh coalbed. The average cleat orientations were measured for each mine (table 1) and plotted according to geographic location (fig. 19). A composite rose diagram (fig. 20) was constructed using the values from table 1. Two distinct peaks are present in the face and butt cleat directions. Two equally dominant fundametal cleat systems with directional trends approximately perpendicular are calculated for the study area. These two systems are N 76° W - N 17° E, with a 93° separation; and N 67° W - N 28° E, with a 95° separation.

In southwestern Pennsylvania and northern West Virginia, the cleat systems rotate clockwise from south to north. In figure 20, the dominant N 17° E direction is composed of the measurements from mines in the southern portion of the area (Nos. 8 to 18 with the exception of No. 9), and the dominant N 28° E direction is composed of the measurements from mines in the northern portion of the area (Nos. 1 to 7 plus 9). The geographic plot of the cleat systems (fig. 19) gives a more detailed picture of the cleat rotation on a mine-to-mine basis.

TABLE 1. - Cleat systems of 18 mines surveyed

No.	Mine name	Face cleat	Butt cleat
North:			
1	Montour 4	N 65° W	N 25° E
2	Mathies	N 65° W	N 27° E
3	Westland	N 70° W	N 25° E
4	Somerset No. 60	N 62° W	N 30° E
5	Vesta No. 5	N 66° W	N 30° E
6	Marianna No. 58	N 68° W	N 28° E
7	Gateway	N 68° W	N 28° E
8	Shannopin	N 73° W	N 18° E
9	Humphrey No. 7	N 70° W	N 27° E
10	Pursglove No. 15	N 72° W	N 19° E
11	Blacksville No. 1	N 75° W	N 20° E
12	Blacksville No. 2	N 77° W	N 17° E
13	Osage No. 3	N 75° W	N 17° E
14	Arkwright	N 79° W	N 12° E
15	Federal No. 2	N 77° W	N 17° E
16	Consol No. 93	N 73° W	N 18° E
17	Loveridge	N 80° W	N 15° E
South: 18	Consol No. 20	N 78° W	N 12° E

A slight counterclockwise rotation of the cleat from east to west was also noted. Starting in the eastern part of the study area with Humphrey No. 7 (N 70° W), and continuing westward to Blacksville No. 1 (N 75° W) and Blacksville No. 2 (N 77° W) mines, the face cleat rotates 7°. A similar rotation was detected between Consol No. 93 mine (N 73° W) and the Loveridge mine (N 80° W) to the west, and in the northernmost part of the study area between the Mathies mine (N 65° W) in the east and the Westland mine (N 70° W) in the west.

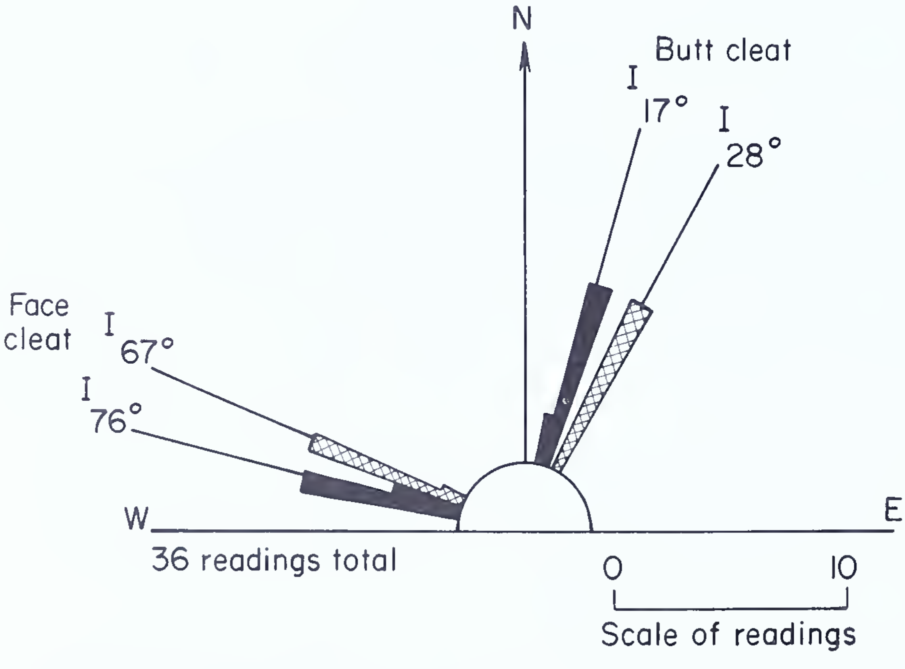

FIGURE 20. - Composite rose diagram of cleat orientation in 18 mines surveyed.

Relationship of Local Structure to Cleat Orientation

Cleat orientation and local structure are closely related. The butt cleats tend to be parallel to the axial trends of folds, whereas the face cleats are perpendicular to the axial trends. This has been noted not only in the Pittsburgh coalbed but also in the Pocahontas No. 3 (Virginia), the Lower Kittanning (Pennsylvania), and the Hartshorne (Oklahoma) coalbeds (75).

A good example of the relationship between local structure and cleat orientation in the Pittsburgh coalbed can be observed in the Pursglove No. 15 mine, located in Monongalia County, W. Va., between the area's two dominant structural features--the Fayette anticline and the Lambert syncline (fig. 21). Cleat orientations measured in the mine define a N 72° W - N 19° E fundamental system. The structural strike within this portion of the mine averages N 24° E, close to the N 19° E strike of the butt cleat. The structural dip is N 76° W, similar to the N 72° W trend of the face cleat. Similar (±10°) relationships between cleat orientation and local structural trends are observed for the majority of the mines surveyed.

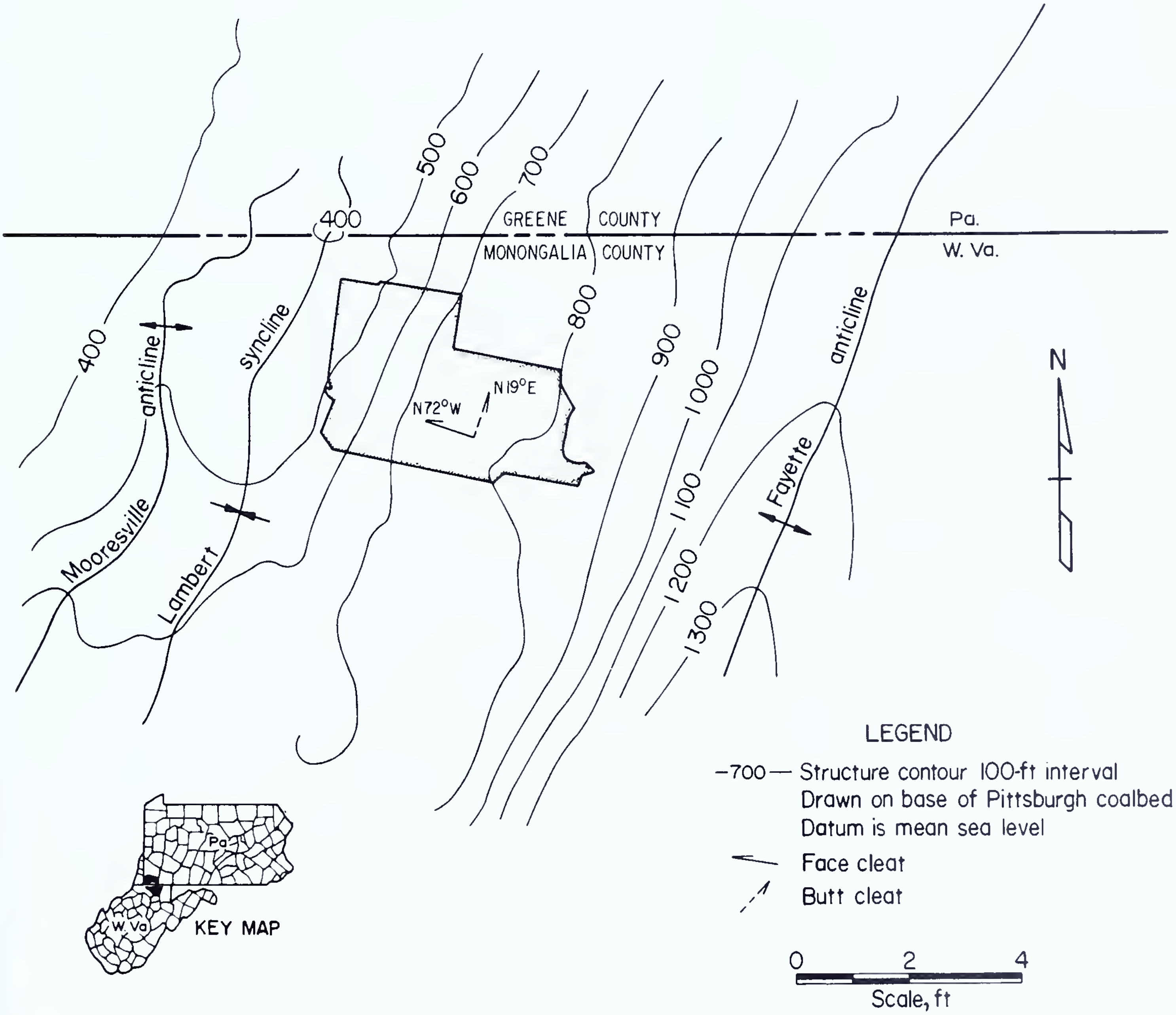

FIGURE 21. - Relationship between local structure and cleat orientation in the Pursglove No. 15 mine, Monongalia County, W. Va.

Geologic Factors Affecting Methane Emission

The Pittsburgh coalbed is a gassy coalbed. According to Irani (50-51) the five counties in the United States producing the most coal gas are--

	MM ft^3/d
Monongalia County, W. Va.	40.7
Marion County, W. Va.	23.1
Buchanan County, Va.	22.1
Washington County, Pa.	12.4
Greene County, Pa.	11.7

Four of these counties are within the study area. They have a total gas production of 87.9 MM ft^3/d; approximately 95 percent is from mining in the Pittsburgh coalbed. Also Kim (60-61) has estimated that the Pittsburgh coalbed in southwestern Pennsylvania (over an area of 575 square miles) contains over 500 billion ft^3 of methane in the virgin coal.

Analysis of a number of gas samples collected from horizontal holes drilled from active faces into virgin coal (59) showed that their methane contents ranged from 84 to 96 percent (table 2).

TABLE 2. - Composition of gas from the Pittsburgh coalbed, percent

Gas	Sample 1	Sample 2	Sample 3	Sample 4
CH_4	88.91	95.86	93.85	84.4
C_2H_6	.04	1.08	.04	-
CO_2	10.97	2.54	4.75	14.75
O_2	.04	.06	.05	.02
N_2	.05	.46	1.20	.65

Although the total effect of the geology of a coalbed on its methane emission is still not completely understood, considerable progress has been made in identifying certain controlling factors. Kissell and Bielicki (64) have found that an unfractured "solid" block of coal has a very low permeability, in contrast to high permeability in the coalbed where fracturing is extensive. The density of the fractures and the permeability of the coalbed depend on the coal rank. The low-volatile coals tend to be the most highly fractured. In a given coalbed, fractures are not uniform in size or spacing. This could be due to such factors as the degree of folding and faulting, proximity to fold axes, and the thickness of overburden. The in situ fracture spacing calculated for the Pittsburgh coalbed is 8 cm, as compared with 4.5 cm for the Pocahontas No. 3 coalbed, although observed fracture spacings may vary widely from these calculations.

Permeability should be greatest in the face cleat direction. In one area of a mine operating in the Pittsburgh coalbed, the methane emission from the solid ribs was significantly higher than the emission from the working face. It was observed that the rib intersected the face cleats and that the working face was draining the less permeable butt cleats (64).

Measurements by Parsons and Dahl (82) of the lateral compressive stresses in strata adjacent to the Pittsburgh coalbed showed that the major lateral stress is in an east-west direction, nearly perpendicular to the butt cleat direction. They concluded that the butt cleats are squeezed more tightly, reducing the permeability even more.

These observations show the importance that cleat plays in determining "directional permeability." Any horizontal drilling in mines to degasify an area must take into account the preferred flow due to directional permeability. Bureau research has shown that a hole drilled into the coalbed perpendicular to the face cleat could yield from 2.5 to 10 times as much gas as a hole drilled perpendicular to the butt cleat. At the Federal No. 2 mine in Monongalia County, three holes were drilled perpendicular to the face cleat and a fourth was drilled parallel to it (fig. 22). The hole drilled parallel had the lowest gas pressure, whereas the holes drilled perpendicular to the face cleat maintained their sustained higher gas pressures even after producing gas for as much as 45 days. This difference in emission is undoubtedly due to the difference between the face cleats, which are much longer and more continuous fractures exposing larger surface areas, and the shorter butt cleats, which frequently terminate against the face cleat.

Other geologic factors also influence gas emission from the coalbed. The amount of overburden is known to be important, but no specific relationship can be established until more accurate gas emission data are available from operating mines. Greater overburden pressures that may tend to close fractures and reduce permeability may be compensated for by a greater gas content of the deeper coals.

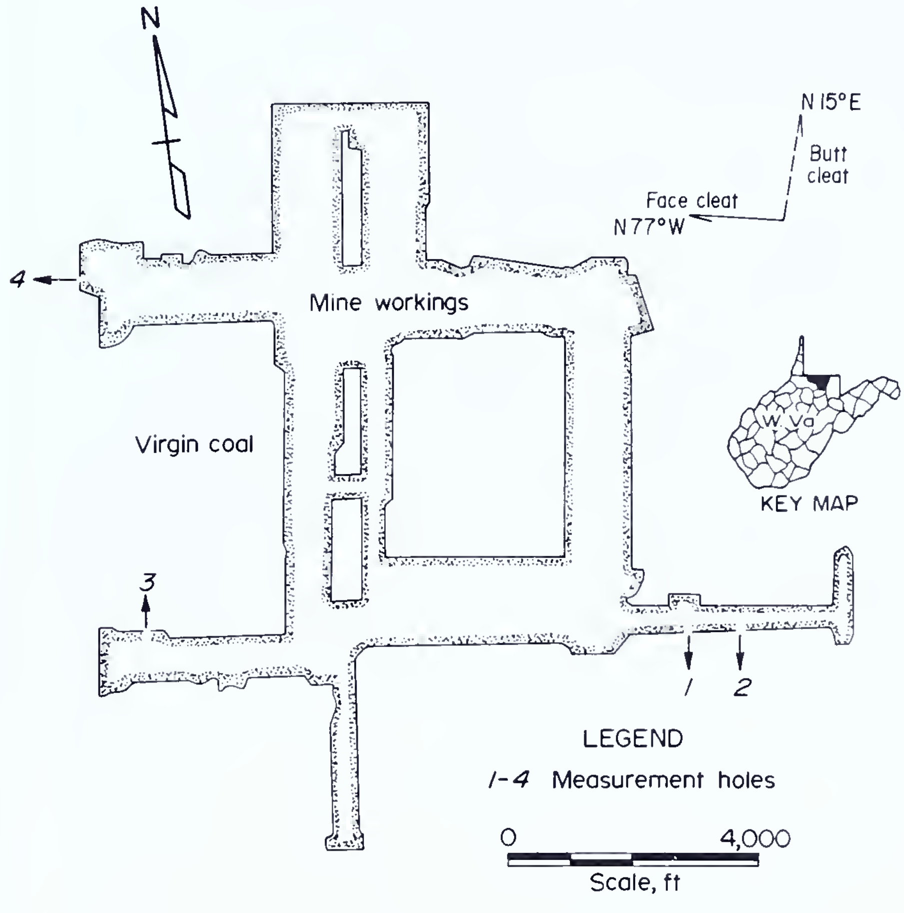

FIGURE 22. - Map of Federal No. 2 mine showing horizontally drilled holes and cleat directions.

Friability of the coal also affects methane emission. A core from the Beckley or Pocahontas No. 3 coalbed (both of which are friable), when allowed to degasify in a sealed container, gives off approximately 94 percent of its total gas content, whereas the same amount of Pittsburgh coal (which is blocky) under the same conditions gives off only 60 to 65 percent of its total gas. This also may be due to the closer cleat spacing in the

Beckley and Pocahontas No. 3 (1/4 inch) coalbeds, as compared with the Pittsburgh coalbed (1 inch).

Geologic structure can also affect gas emission through its effect on waterflow. Even a dip of less than 1° can decrease the flow of gas because any water in the coal must be displaced uphill before gas can flow freely.

Example of Geology-Related Problems in a Working Mine

Typical structure-related problems were studied at Somerset No. 60 mine (76), which was being developed down the northwest flank of the Amity anticline towards a syncline (fig. 23). Water has been accumulating at the face of entries being driven to the northwest, which dip into the working face. Once the axis of the syncline is crossed, the floor will dip away from the face, allowing the water to run off.

The N 62° W (face) and N 30° E (butt) cleat system is nearly orthogonal. The measured rock joint orientations are between N 57° W and N 75° W, corresponding roughly to the face cleat. Mining was originally parallel to the cleat orientations but at present is 45° to the previous working. According to the operators, this gives more stable ribs and roof.

The immediate roof is generally coal. A weak slickensided claystone, generally up to 12 inches thick and overlying the coal, is removed during mining, leaving the "stable" rider coal. Study of roof falls shows the weak strata to be either micaceous sandstone with thinly interbedded shale, or alternating coals and slickensided claystones.

In the western part of the mine workings there are sand channels that completely cut out the coal. To investigate roof conditions and the probability of sandstone channels in the area of future advancement adjacent to the active mine workings, a fence diagram (fig. 24) was constructed using data on the 40 feet of strata immediately above the Pittsburgh coalbed. The probability of the coal being cut out increases in areas where the rock type directly above the coal is predominantly sandstone and where the base of the sandstone approaches the top of the coal. Based on this consideration and on core data, a sandstone cutout probability map (fig. 25) was constructed.

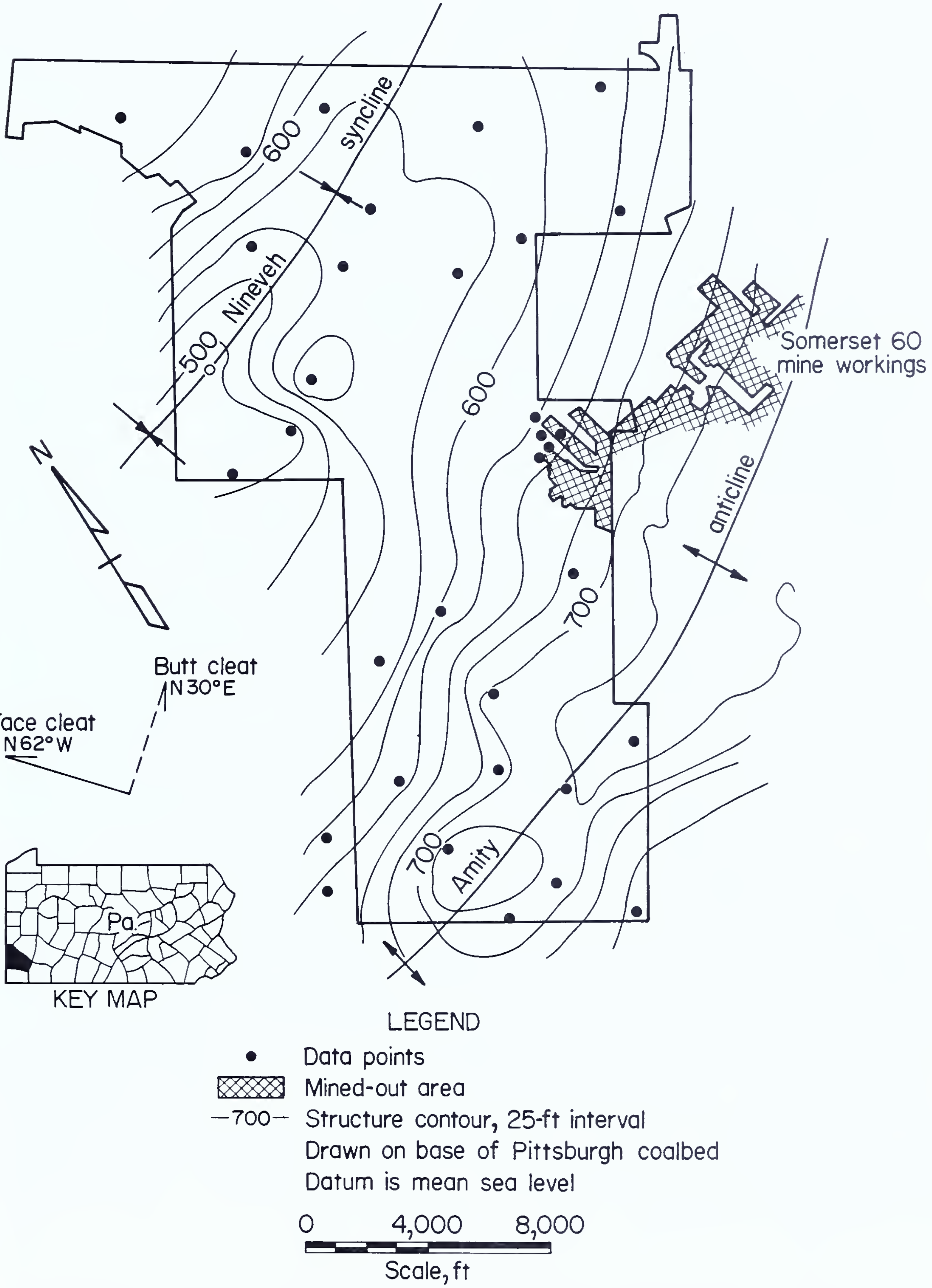

FIGURE 23. - Structure map drawn on the base of the Pittsburgh coalbed for the area adjacent to the active workings of the Somerset No. 60 mine.

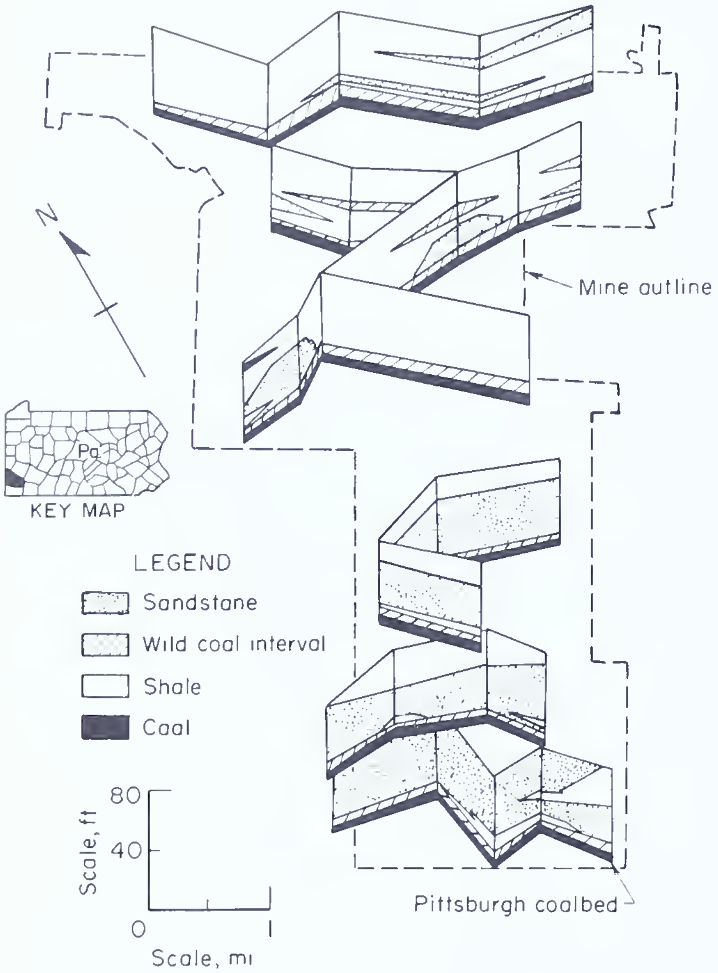

FIGURE 24. - Fence diagram of the strata directly above the Pittsburgh coalbed adjacent to the active workings of the Somerset No. 60 mine.

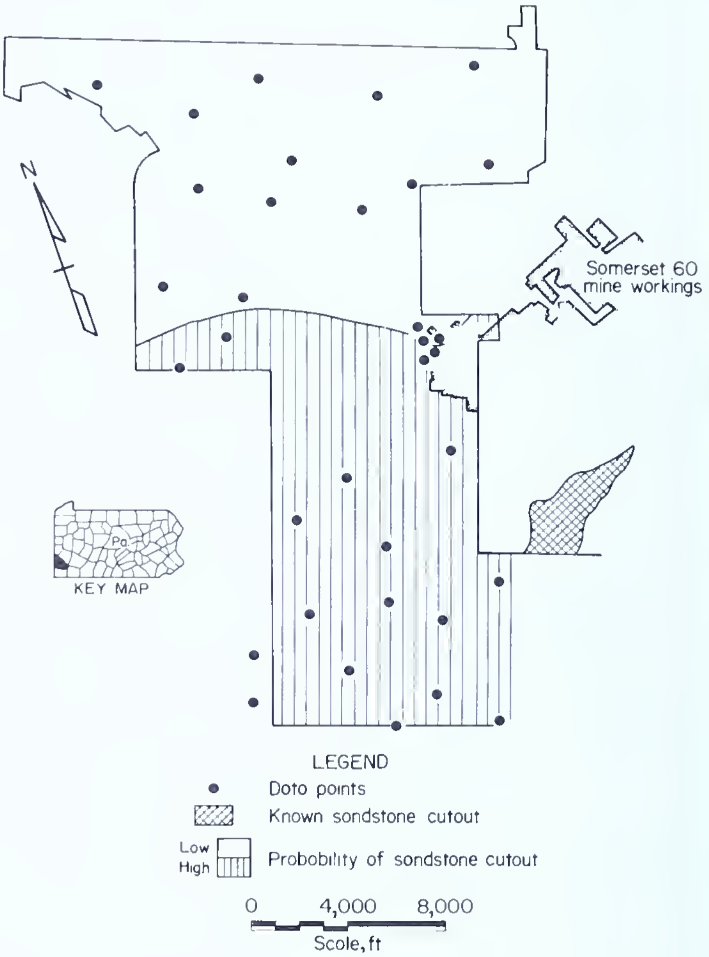

FIGURE 25. - Sandstone channel probability map of the area adjacent to the active workings of the Somerset No. 60 mine.

Zones of abrupt lithologic change often coincide with areas of unstable roof and high gas emission (53, 58, 75-76). The significant lithologic changes that can occur within a very short horizontal distance above the Pittsburgh coalbed are exemplified in figure 26 by two core holes (TH1 and TH2) 620 feet apart and on opposite sides of the boundary between the zones of low and high probability shown in figure 25. The rapid change in lithology is due to the removal of stream erosion of approximately 20 feet of original sediments at the location of the TH2 hole along a stream channel that was subsequently filled with sand. More core drilling in the area adjacent to the active workings of the Somerset No. 60 mine could provide additional data to substantially refine the prediction of specific problem areas. The practice of spacing core holes 3,000 feet or more apart makes correlations and predictions difficult, especially where there are rapid changes in lithology and sedimentation patterns.

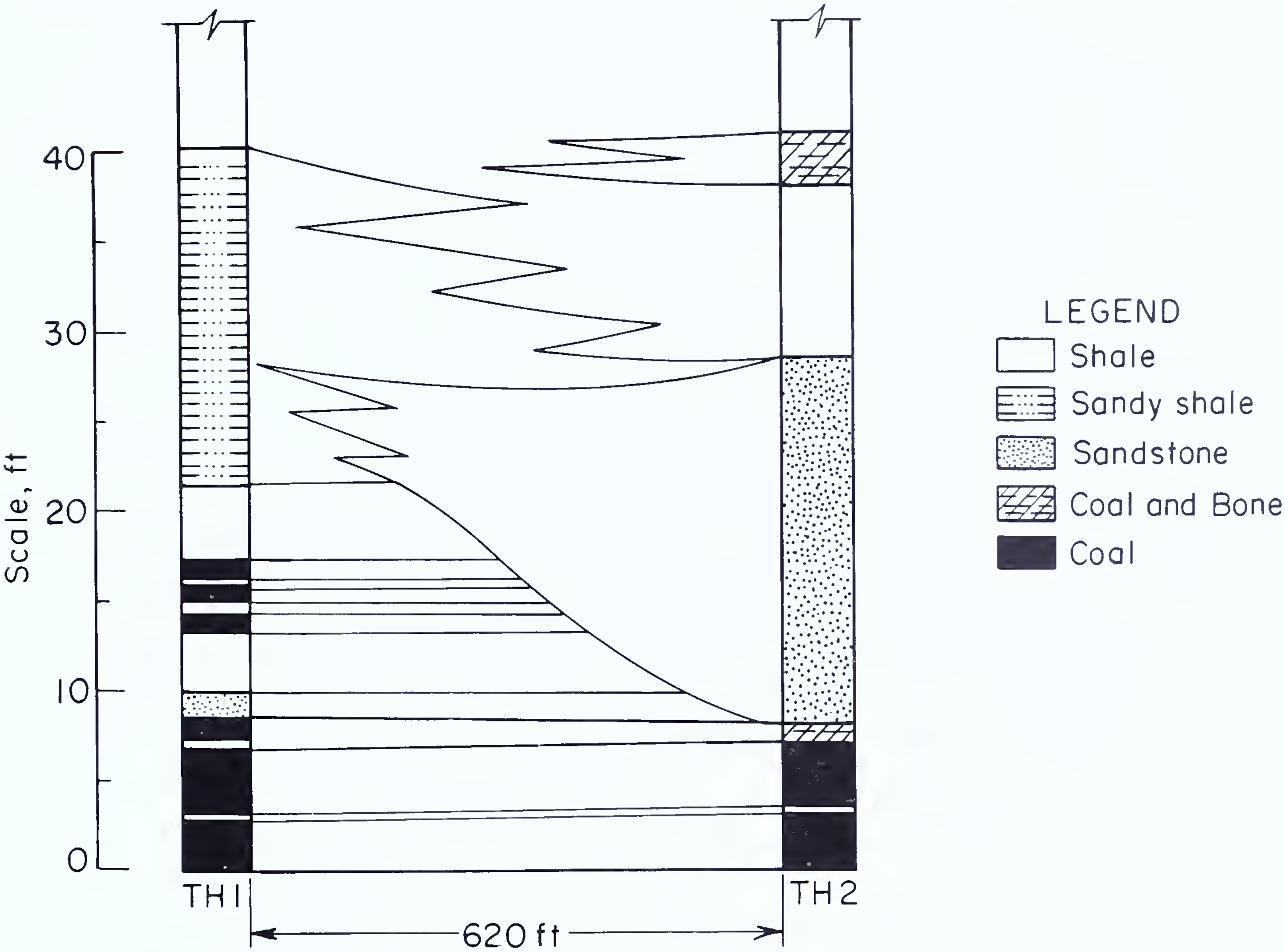

FIGURE 26. - Rapid lateral variation in the strata directly above the Pittsburgh coalbed.

Directly overlying the main bench (mined portion) of the Pittsburgh coalbed is an interval of variable thickness known as "draw slate" (fig. 27). This rock interval has very little strength and commonly fails, resulting in sudden gas emissions and rock haulage problems. Most miners prefer to anchor roof bolts in the more competent rock above the draw slate. The minimum bolt length that would be necessary to anchor into competent rock above the "draw slate" unit in any area can be determined from isopach maps like figure 27.

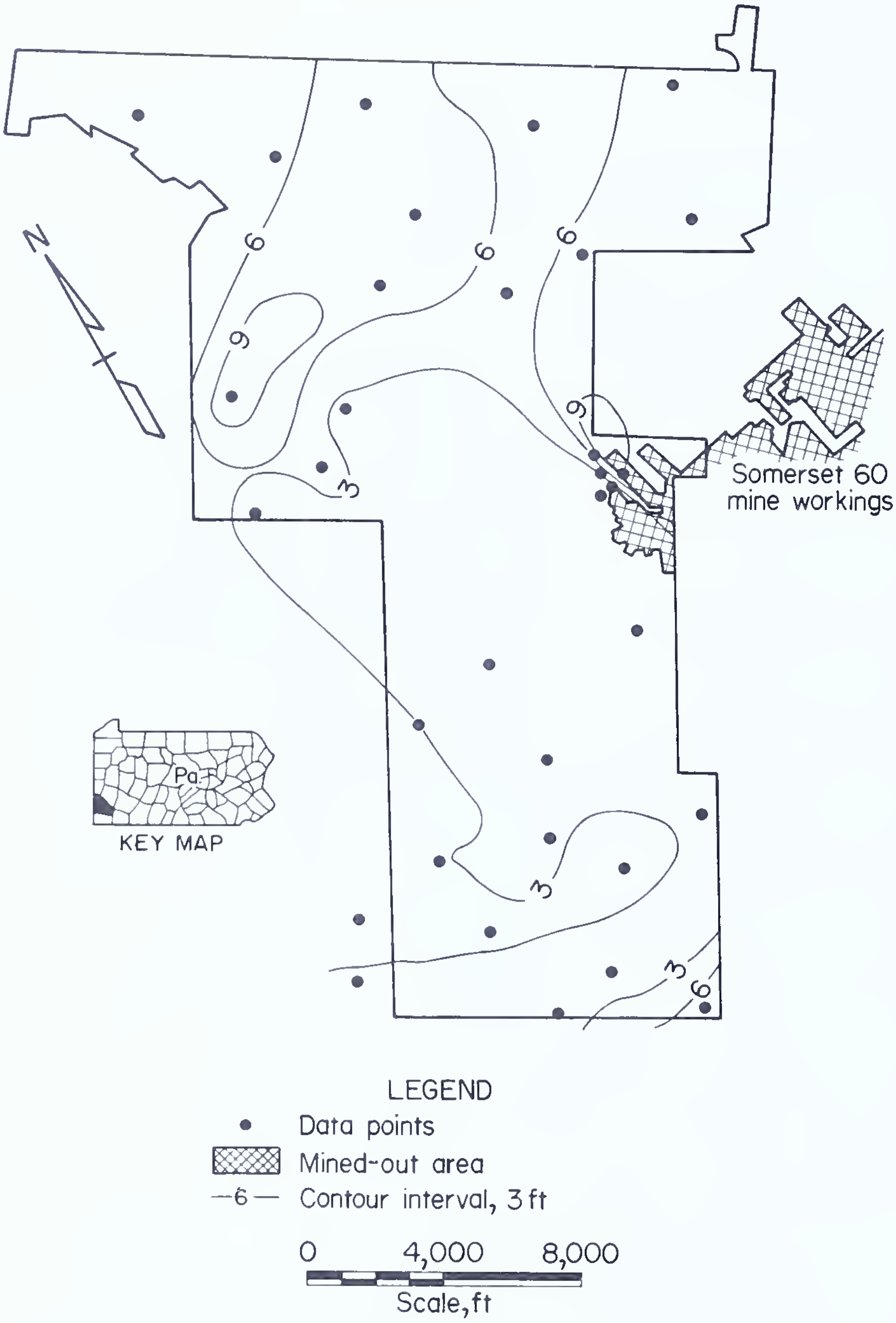

FIGURE 27. - Isopach of "draw slate" above the Pittsburgh coalbed in the area adjacent to the active workings of the Somerset No. 60 mine.

DETERMINATION AND ANALYSIS OF JOINTS AND PHOTOLINEARS

The frequency, character, and prominence of jointing in surface rock exposures vary greatly, depending on brittleness and on the susceptibility of each rock type to the compressional and tensional forces exerted on the earth's crust. According to Nickelsen and Hough (80), jointing due to increasing tectonic forces affects coal first, then shale and limestone, and lastly sandstone. This is evident from the relative spacing of joints in the various rock types. Coal cleats generally have the closest spacing, followed by shale, limestone, and then sandstone in which the joints are the most widely spaced and most prominent. Inspection of the joint measurements for each rock type gives an overall view of the principal trends.

Photolinears are zones of weakness that generally correlate with measured joint trends and may or may not be actual fractures observed in the field. In areas of heavy vegetation or few outcrops, or during periods of bad weather for fieldwork, photolinear analysis is an alternative to the measurement of surface joints.

The directional trends established by the various techniques indicate directions of inherent weakness in a coalbed and the rock surrounding it. An analysis of the fundamental directional systems in a virgin area prior to mine development can provide an estimate of the cleat system in a coalbed underground. This in turn determines the most efficient spacing of degasification holes for maximum gas flow, and to some extent, determines the most efficient mine development in directions that can minimize problems such as rib spalling and water and gas influx.

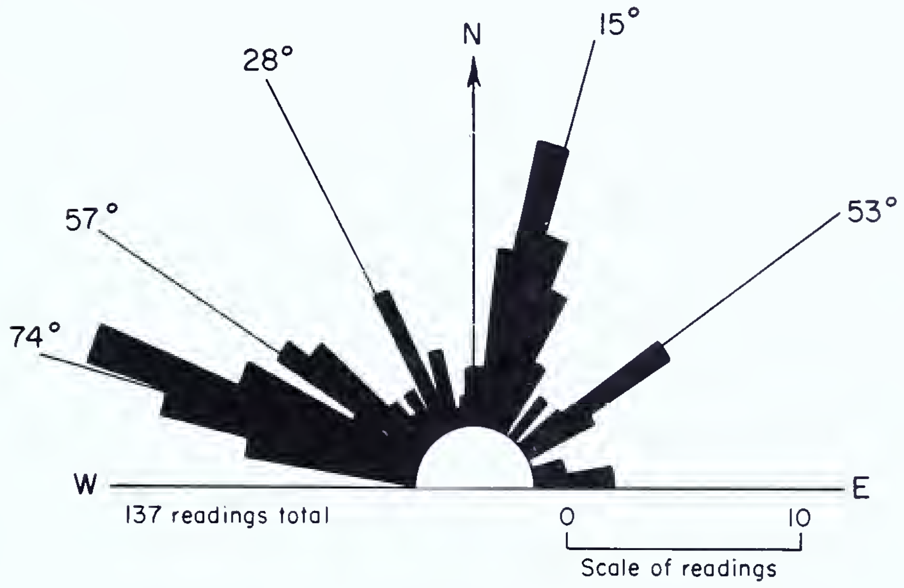

FIGURE 28. - Rose diagram of surface joint trends from the New Freeport quadrangle, Pennsylvania.

Coal is the rock type most susceptible to the tectonic forces that produce directional trends that reflect structural weakness. The face and butt cleats measured in coal underground are the direct result of these tectonic forces and are directly related to the regional structural trends. Because of the need to estimate the directional trend of cleat underground and the established relationship of cleat to structure, the cleat data are used as a standard against which to judge the reliability of data obtained by other methods.

Surface Joint Determination

Surface joints were measured over the thirty-nine 7-1/2-minute quadrangle study area in southwestern Pennsylvania and northern West Virginia. An average of 120 joint readings were taken per quadrangle with a minimum of 100 readings per quadrangle and no more than 10 readings at a single outcrop. Rock types and quality of joints were noted at each outcrop. The directions were read as azimuths using damped Brunton compasses corrected for magnetic declination. To evaluate the principal directional trends, the data from each quadrangle were plotted individually on rose diagrams (fig. 28). By plotting only the dominant trends from each individual quadrangle on a single rose plot, a composite rose diagram (fig. 29) of surface joint trends for the study area was constructed. Joint orientations by tier (fig. 30) and corresponding counties from north to south are given in table 3.

Surface Joint Analysis

It was determined from the data shown in figure 29 that there are three major directional trends to the west and four to the east (table 4). The number directly above the directional trends in table 4 gives the order of dominance within the group, based on the number of readings comprising the peaks on figure 29. The assigning of the same order of dominance to two readings in the same group indicates equally strong directional trends.

TABLE 3. - Average surface joint orientations, by county

Tier	County	1	2	3	4	5	6	7	8	9
				WEST						
1, 2, 3	Washington..........	N 6° W	N 21° W	N 33° W	-	N 49° W	N 57° W	N 73° W	-	N 85° W
4, 5	Greene..............	-	N 19° W	N 28° W	N 40° W	-	N 58° W	N 75° W	N 81° W	-
6	Wetzel and Monongalia	-	-	-	-	N 51° W	-	N 67° W	N 80° W	N 87° W
7	Marion and Monongalia	N 5° W	N 20° W	-	-	N 51° W	-	N 68° W	N 81° W	-
8	Marion and Harrison..	N 7° W	-	N 35° W	-	N 51° W	N 61° W	-	N 80° W	N 89° W
				EAST						
1, 2, 3	Washington..........	N 7° E	-	N 19° E	N 29° E	N 37° E	N 46° E	N 63° E	N 72° E	N 89° E
4, 5	Greene..............	N 2° E	N 14° E	N 22° E	N 28° E	N 38° E	N 49° E	-	-	N 80° E
6	Wetzel and Monongalia	N 5° E	N 13° E	-	N 27° E	-	N 53° E	-	N 72° E	-
7	Marion and Monongalia	N 2° E	N 15° E	-	N 25° E	N 37° E	-	-	N 68° E	N 86° E
8	Marion and Harrison..	N 5° E	N 14° E	-	N 27° E	N 39° E	-	N 59° E	N 72° E	N 83° E

NOTE.--Numbered trends are arranged within the 2 directional groups (east and west) by increasing divergence from north and not by their order of dominance. Trends within the same vertical column of a group are assumed correlative. Directional data from the individual quadrangles are tabulated in appendix B.

TABLE 4. - Principal surface joint trends in order of dominance

West		East			
I	III	I	II	III	IV
N 57° W	N 34° W	N 15° E	N 27° E	N 37° E	N 47° E
N 76° W	-	-	-	-	-

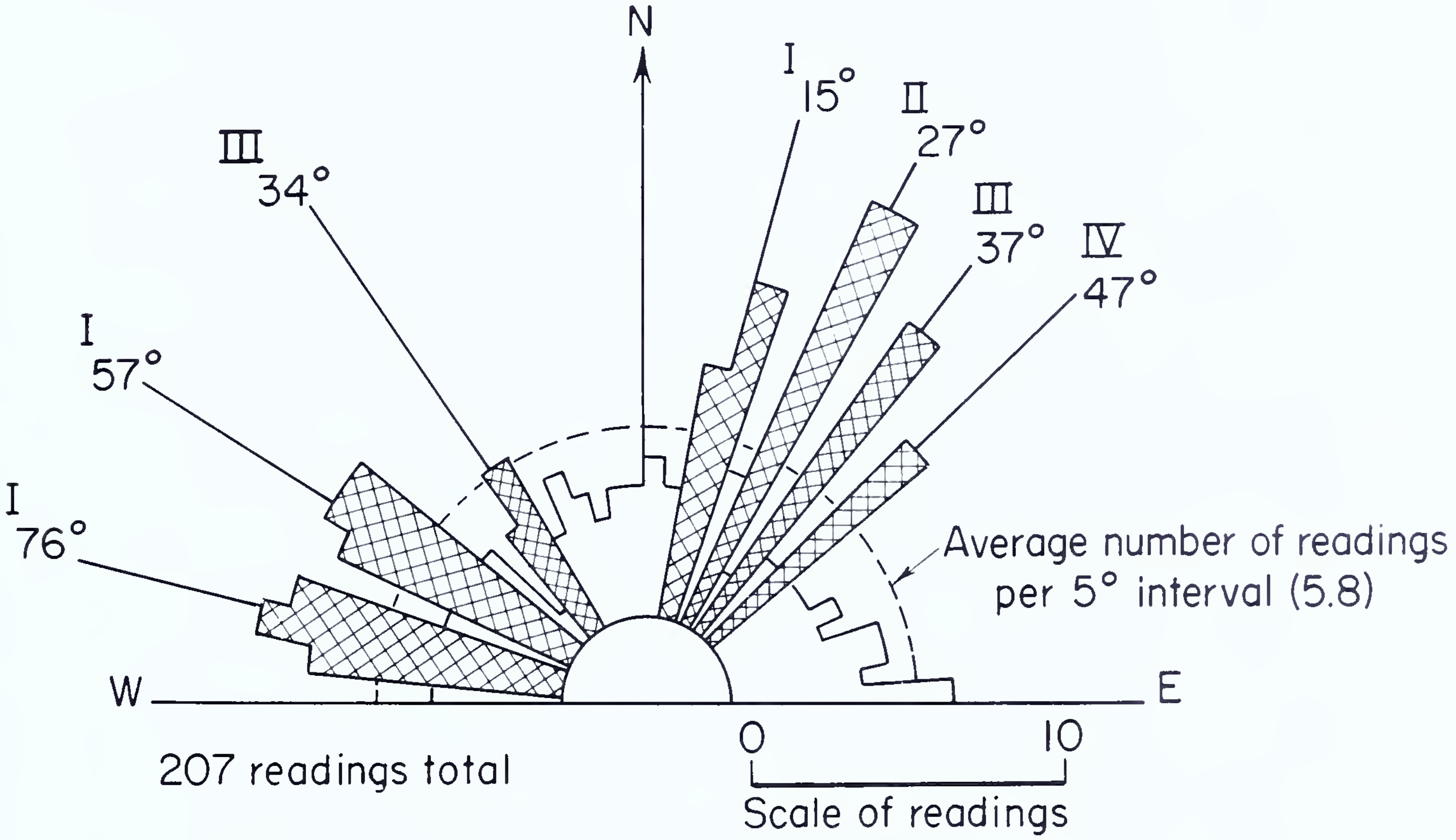

FIGURE 29. - Composite rose diagram of principal surface joint trends.

The principal directional trends listed in table 4 can be paired to form six fundamental joint systems:

1. *N 57° W' and N 27° E'' with an 84° separation.
2. *N 57° W' and N 15° E' with a 72° separation.
3. *N 57° W' and N 37° E''' with a 94° separation.
4. *N 76° W' and N 15° E' with a 91° separation.
5. *N 76° W' and N 27° E'' with a 103° separation.
6. *N 34° W''' and N 47° E'V with an 81° separation.

The superscripts in Roman numerals indicate the order of dominance, and the asterisks indicate the most dominant trend of each system. Two surface joint systems (Nos. 2 and 4) are composed of joint sets of the first order of dominance. Both systems are composed of the N 15° E' set. System 4, with a 91° separation, more closely approaches the ideal fundamental system's 90° separation than does system 2 with a 72° separation. System 4 (*N 76° W' - N 15° E') is quite similar in orientation to the *N 76° W' - N 17° E' cleat system established underground. The *N 76° W' set of system 4 is the most dominant set of system 4 and parallels the face cleat. The N 76° W' set could also be paired with the N 27° E'' set (system 5), but the separation of 103°

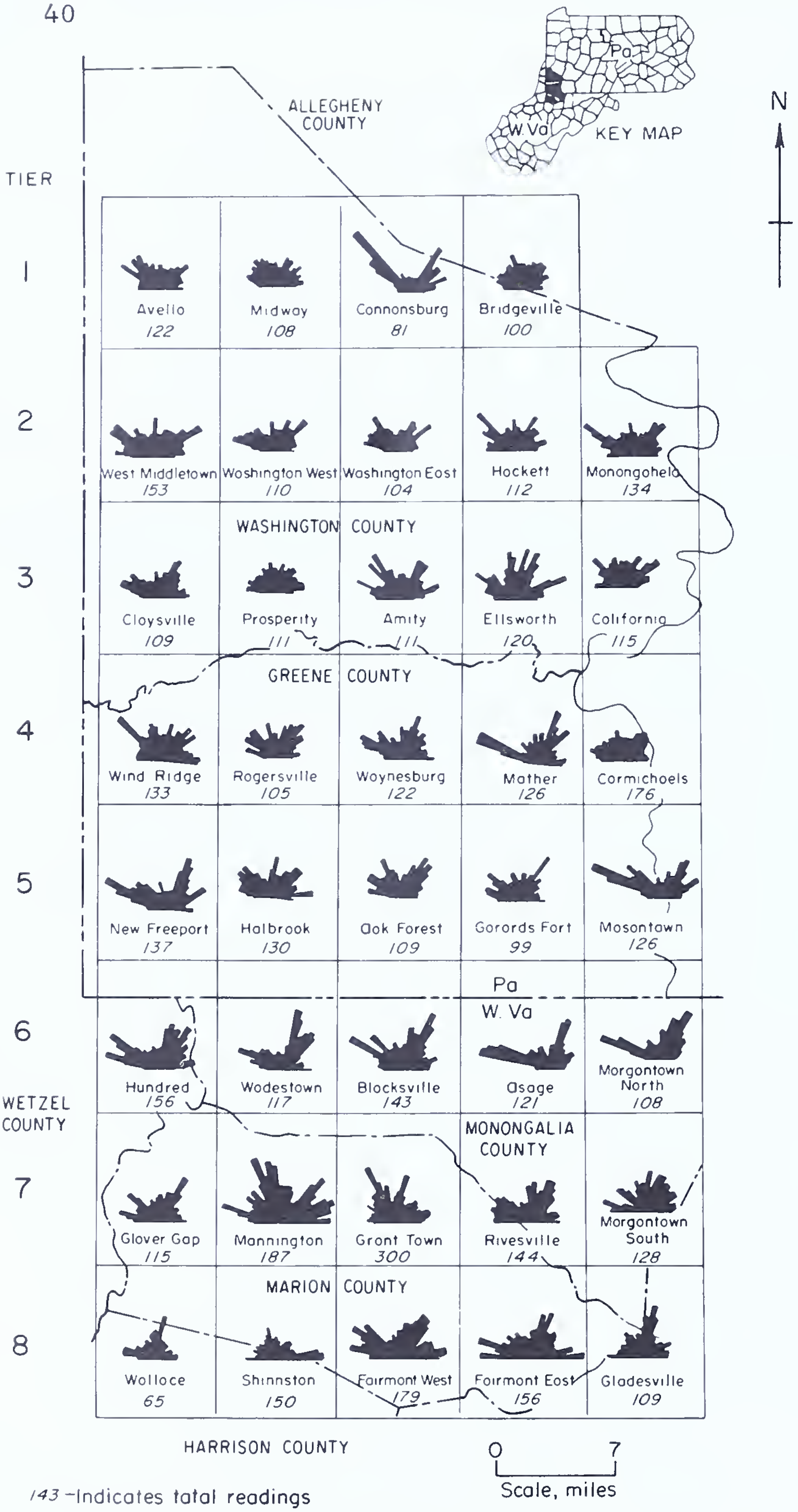

FIGURE 30. - Rose diagrams of surface joints for 39 quadrangles.

is greater and the N 27° E'' set is less dominant than the N 15° E' set.

The N 57° W' set, if not paired with N 15° E', can be paired with N 27° E'' (system 1) for an 84° separation or with N 37° E''' (system 3) for a 94° separation. System 1 (*N 57° W' - N 27° E'') is reasonably similar to the *N 67° W' - N 28° E' cleat system established underground. System 3 (*N 57° W' - N 37° E'''), while not substantially dissimilar from the *N 67° W' - N 28° E' cleat system, is, however, composed of one set of the third order of dominance. The *N 57° W' set of systems 1 and 3 is the most dominant set of the systems and is reasonably similar to the face cleat orientation.

The most dominant eastern components (N 15° E' and N 27° E'') closely parallel the strike of the major structural axes of the area, and the western trend is nearly perpendicular to the axes. Therefore, the systems are probably directly related to the regional structural deformation. The sixth surface joint system (*N 34° W''' - N 47° E^{IV}) may also be related to the regional structure, although it is composed of sets of the third and fourth order of dominance and not oriented parallel to the cleat directions. This system is oriented at approximately 45° to the *N 76° W' - N 15° E' system, which is within the theoretical angle of shears to the dominant trends.

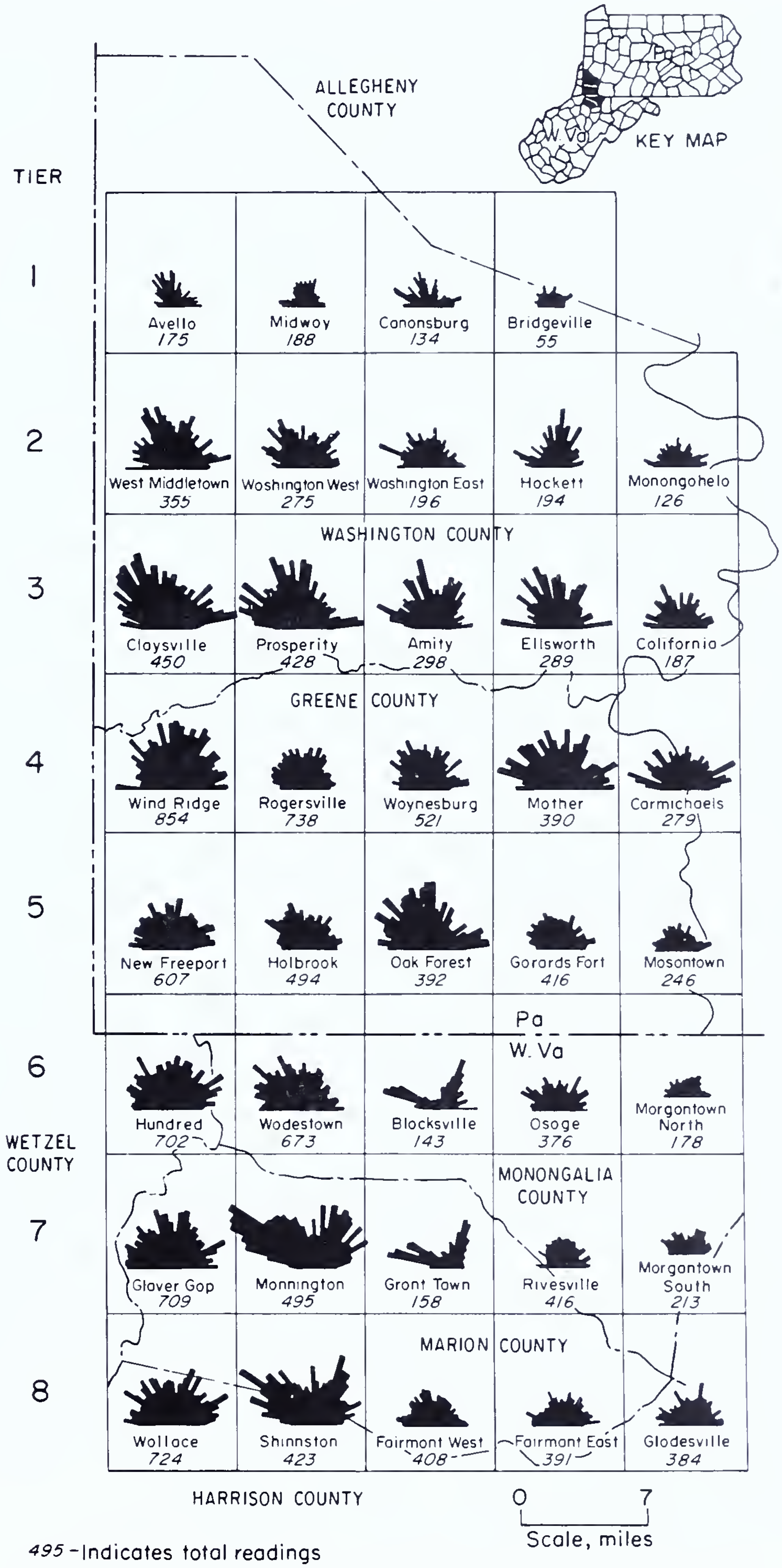

FIGURE 31. - Rose diagram of photolinears for 39 quadrangles.

Additional evidence for the correlation of jointing with regional structure is the clockwise rotation of the joint trends in the study area; this is also observed for the trends of the major structural axes. The rose diagrams of the joint measurements from the individual quadrangles assembled in figure 30 illustrate the shift of the joint trends throughout the area.

SUMMARY

The Pittsburgh coalbed is one of the largest potential fuel resources in the world with respect to total tonnage of coal and the associated gas reserves. To aid in the efficient utilization of this deposit, a study was made of the southwestern Pennsylvania and norther West Virginia area which it underlies. The primary objective was to identify geologic factors that interfere with efficient mining and especially those factors that influence gas migration in the coalbed.

For this purpose, a map was prepared of all known sandstone bodies that intersect the coalbed. A correlation was found between areas of thicker sandstone and the occurrence of sandstone channels cutting into the coal. Prediction of sandstone channel trends is commonly hindered by the lack of sufficient subsurface data. Core drilling on the usual mile centers may entirely miss some of the sinuous, narrow sandstone channels.

Clay veins were found and mapped in eight of the mines surveyed and tend to be clustered along the axes of synclines. Clay veins have been observed more frequently near channel sandstone bodies. Clay veins tend to intersect, forming boxlike cells that prevent gas migration. A hole drilled through two clay veins had pressures of 220 and 263 lb/in^2 on the virgin side and 0 lb/in^2 on the mined side (41). X-ray diffraction analysis of clay vein material and roof and floor rock indicates that in the mines investigated the clay material was injected after coalification from the roof and not from the floor.

An isopach map of the Pittsburgh coalbed was constructed from more than 3,000 data points. Wherever possible, strip mines were located and mapped. The coalbed thickness trends were oriented northeast to southwest, closely paralleling the regional structure. Areas of thick coal (8 feet plus) generally were located near synclinal troughs. Some areas of thin coal (less than 4 feet) were located near the axes of the anticlines. Several other areas of low or thin coal had a sinuous pattern, suggesting a possible relation to ancient stream systems.

A fence diagram was prepared of the strata above the Pittsburgh coalbed. The predominant rock type directly above the coalbed is a "draw slate" composed of thinly bedded, dark gray to black, fissile carbonaceous shale, coal, and sandstone. This unstable unit is generally less than 4 feet thick but may be as much as 12 feet thick. In Monongalia and Marion Counties, the rock above the draw slate is usually limestone and shale. In Greene County, limestone predominates in the south and sandstone in the north, reaching a maximum thickness of 80 feet. In Washington County there is a preponderance of limestone in the southwest, sandstone in the south and center, and shale in the north.

A close relationship between overburden thickness and structure was established in Pennsylvania. In general, the coalbed was nearer to the surface along the axes of anticlines and deeper along the troughs of synclines. The overburden thickness ranged from zero at outcrop along the eastern edge of the study area to a maximum of 1,500 feet in western Greene and Monongalia Counties. The relationship was less well developed in West Virginia.

Cleat surveys were completed in 18 mines operating in the Pittsburgh coalbed. Two similar, but slightly different cleat system (*N 76° W and N 17° E, *N 67° W and N 28° E) were established for the area, amounting to approximately a 10° clockwise rotation from south to north. A slight counterclockwise rotation of 4° to 7° was detected from east to west. A strong relationship was apparent between the cleat orientations and the local and regional structure. Face cleats tended to be perpendicular to the axial trends of folds, and the butt cleat tended to be parallel to the axial trends. The rotation observed for the cleat directions in general matches the rotation of the structural trends.

The need for estimating the cleat systems in areas of virgin coal prompted the measurement and analysis of surface joints and the analysis of photolinears from infrared photographs and photoindex sheets. Although all three techniques provide reliable regional estimates of the cleat systems, surface joints provide the best estimate, especially on a local basis. Ronchi inspection of photoindex sheets is the fastest and cheapest method, but the level of confidence is better for the two other techniques.

This report is a study of a large area and the problems that may be encountered in mining coal. The problems that can occur were noted, and possible solutions and methods of detection of the trouble areas are offered. The project was implemented because a number of studies had been conducted on individual mines in the area and on individual quadrangles and selected areas, but no overall geologic study of this important coalbed had been attempted. Eighteen coal mines were studied underground, 39 quadrangles were mapped for surface joints and photolinears, and more than 3,000 core log descriptions were collected.

It is hoped that the results presented in this report can serve as a framework for future mine planning and operations in the Pittsburgh coalbed. More detailed geologic studies dealing with specific problems of individual mines can be conducted as outlined by McCulloch and Deul (74). Because the methodology developed in this study can be applied to other areas, especially where there will be more underground coal mining, this approach is recommended for consideration by the mining geologists and engineers responsible for mine planning.

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